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WIND VELOCITY PROFILES MEASURED BY THE SMOKE-TRAIL METHOD AT THE EASTERN TEST RANGE, 1962

by James C. Manning, Robert M. Henry, and Robert W. Miller

Langley Research Center
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SUMMARY

Twenty-five detailed wind profiles measured by the smoke-trail technique at Cape Kennedy during the year 1962 are presented as plots of west-to-east and south-to-north velocity components at height intervals of 25 meters. The altitude ranges of the profiles vary; the overall range is approximately 2 to 21 kilometers. All measurements presented were made in the last half of the year. The measurements were made under a wide variety of wind conditions, and they include velocities in excess of the annual 95-percent extreme value. Most profiles have low to moderate peak values but exhibit considerable small-scale variations. The measurement technique, including recent modifications, and the accuracy of these particular profiles are discussed. Data reduction procedures and the discussion of error values are presented in appendixes.

INTRODUCTION

The smoke-trail wind-meaurement technique described in reference 1 was developed to supply accurate measurements of the small-scale variations of wind velocity with altitude. Knowledge of these small-scale variations is needed particularly for dynamic response studies of vertically launched missiles and space systems. The small-scale variations cannot be obtained from present-day conventional balloon sounding methods because of tracking errors, unstable or self-induced motions of the balloons, and the horizontal drift of the balloons during ascent (refs. 1 and 2).

In 1959, a feasibility study of the measurement of wind velocity profiles by the use of smoke trails was undertaken at the Wallops Island Range. This study was followed by a system development program which was concluded in the spring of 1962 and which resulted in the present smoke-trail wind measurement technique. A series of 70 firings was begun at Wallops Island, Virginia, in August 1963 for the purpose of obtaining a climatological sample at that location. Several wind profiles obtained by the smoke-trail technique have been reported in references 1 to 11. Reference 12 contains a collection of profiles for Wallops Island.

In May 1962, a series of 108 firings was begun for the purpose of obtaining a limited climatological sample of detailed wind profiles at the Eastern Test Range (Cape Kennedy). In this publication the basic data from the 25 smoke-trail measurements at the Eastern Test Range (ETR) during the first calendar year of the program, 1962, are presented. In addition, the measurement technique and accuracy are reviewed. Data reduction procedures are outlined in appendix A by Mickey G. Rowe.

MEASUREMENT TECHNIQUE

The basic technique for obtaining detailed wind profiles from smoke trails consists of photographing a visible trail formed by releasing a suitable chemical from a rocket during the coasting portion of its flight and determining the motion of the trail from photogrammetric measurements. The fundamental procedures are described fully in reference 1 and briefly in references 2 to 4. The present report discusses only changes in or additions to the procedure. Most of the changes which have been made in the measurement technique described in reference 1 were reported in reference 12, but will be described herein as they apply to the Eastern Test Range.

ETR Camera Network

The smoke-trail camera network at the ETR consists of three camera stations, False Cape, Williams Point, and Patrick Air Force Base, as illustrated in figure 1. The False Cape station is located approximately 15 kilometers NNW of the launch point. Williams Point is 23 kilometers W, and the Patrick station is 26 kilometers SSW of the launch point.

The False Cape – Williams Point base line is 23 kilometers in length at an azimuth of 50°, and the Williams Point – Patrick base line is 29 kilometers in length at an azimuth of 147°. The launch point is nearer and less favorably located with respect to the False Cape – Williams Point base line than the Williams Point – Patrick line. It is preferable to use the Williams Point – Patrick camera pair when possible.

The Smoke Vehicle

The data in this report, which are summarized in table I, were derived primarily from the smoke trails produced by Nike smoke vehicles; however, the data from one trail were derived from the exhaust trail of a Saturn rocket. The Nike smoke vehicle used at the Eastern Test Range was essentially a standard Nike rocket motor with a 10° nose cone. The vehicle is described in reference 13.

The smoke-producing chemical used during the period covered by this report (1962) was FS (chlorosulfonic acid-sulfur trioxide) as described in reference 1. Later in the program, a change was made to FM (titanium tetrachloride) which was found to

produce a denser trail at the higher altitudes, although there is a delay of 2 to 3 minutes before full brightness is achieved. A discussion of the relative merits of several smoke-producing chemicals can be found in reference 14.

Data Preparation

Because of the interest in small-scale features of the profile, it is necessary to give great attention to the avoidance of random errors or stray points which might ordinarily be of little concern. In the present application, these errors might be erroneously interpreted as real small-scale features of the atmosphere. The painstaking checking procedures outlined below have been found to be essential in obtaining wind profile data which are satisfactory for structural dynamic studies. A number of checking procedures have been incorporated in the computer program, but many checks still depend on human judgment. The steps in preparing the data for machine processing are the following:

(1) Time synchronization check.- Although the timers used to synchronize the operation of the camera shutters provide timing accurate to a fraction of a second, the recorded frame number may be in error by a whole number, with a resulting error which is a multiple of the 5-second timing interval used at the Eastern Test Range. Time synchronization is checked by comparing the position of the rocket on the various photographs and finally by checking consistency of apparent motion of the trail on successive photographs.

(2) Selection of photographs.- The camera pair having the most readable photographs is selected and then the 1-minute interval having the most readable trail is selected. Three pairs of simultaneous pictures at successive 30-second intervals are then read.

(3) Film reading and editing.- In each picture, the coordinates of the fiducial marks, calibrated focal length marks, and surveyed camera orientation reference marks are read five times each. These readings are averaged to reduce reading error. The trail image in each picture selected is read twice. Since these smoke-trail point readings are not made at fixed intervals, they cannot be averaged or compared point by point.

In order to compare the two corresponding readings, line plots of trail image coordinates are made and compared by superimposing one plot on another, with the plotted fiducial marks alined. Any discrepancies between the two line plots are checked and corrected. In addition, the consistency of movement of the trail coordinates for the successive 30-second intervals is checked, and the plotted trail coordinates are compared visually with the photographs. On the basis of these checks, one corrected reading of the trail coordinates from each of the three pairs of simultaneous photographs is selected for further processing.

Data Reduction

The data reduction procedure is basically the same as that given in reference 1. Additional subroutines have been incorporated to perform an additional coordinate rotation necessitated by a change in surveyed reference arrangements and to minimize the effects of any erroneous points which may still be present in spite of previous checking procedures.

Coordinate rotation.- In the camera orientation and coordinate rotation procedure of reference 1, it was assumed that the cameras and surveyed reference marks all lie in a common horizontal plane. This assumption does not apply to the Eastern Test Range, so an additional coordinate rotation step is used to rotate from the local vertical at each camera station to the local vertical midway between cameras. Thus, the horizontal plane of the final coordinate system of each base line is perpendicular to the vertical at the midpoint of that base line and passes through the two camera locations of that base line.

Machine editing.- Early in the smoke-trail program, it was discovered that a single "wild point" could sometimes cause the program to bypass a large number of correct points, or even produce an incorrect matching of points in the two photographs. This error could result in computation of the coordinates of one of the extraneous ray intersections which is a mathematically correct solution, but is not the physically correct solution corresponding to the actual smoke-trail position. Since this situation could occur as a result of even small errors, such as the operator inadvertently backtracking along the trail (an error which could not be detected by the visual reading check), a series of machine operations was devised to prevent these occurrences. These operations are described in appendix A. The effect of these operations is to reject any point where the elevation angle in the rotated coordinate system appears to be increasing in one photograph but decreasing in the other and, also, to reject any point where the computed height of the trail would decrease along the trail as followed in the order of its formation. Although it is clear that all the points so rejected would have resulted in incorrect velocity computation, it is not possible to determine what the correct value would have been. Therefore, a linear interpolation is performed between the last correct point and the next correct point. With the very large number of points read, linear interpolation does not usually result in appreciable error, but the possibility of error cannot be completely eliminated.

A sample tabulation of the reduced data is given in table II.

ACCURACY OF DATA

Theoretical Error

With the use of the method of reference 1 and the particular parameters appropriate to the Eastern Test Range smoke-trail camera network, the theoretical error for a representative point on the trail can be expressed for the False Cape – Williams Point base line as

$$\sigma_V = 3.89 \times 10^5 \; \sigma_r/\Delta t \tag{1}$$

and for the Williams Point – Patrick base line as

$$\sigma_V = 4.76 \times 10^5 \; \sigma_r/\Delta t \tag{2}$$

where σ_V is the rms vector error of the wind velocity, σ_r the rms film-coordinate error, Δt the time interval, and the constant is nondimensional. These values may be compared with the value of $3.46 \times 10^5 \; \sigma_r/\Delta t$ which was derived for the camera network in use at Wallops Island. It should be noted that these values refer to a particular point and to a perfectly vertical trail. Errors will generally increase with altitude, and they will generally be larger for sloping trails than for vertical trails. From the geometry of the camera network, it is expected that the increases due to trail slope will be greater for the False Cape – Williams Point camera pair.

Empirical Error Estimates

In appendix B, a number of rms difference and error values are presented, and some upper and lower limits of rms vector errors for the Williams Point – Patrick and the False Cape – Williams Point camera pairs are determined. These limit values are given in table III. The data in table III indicate that the actual rms errors do not exceed about 1/2 m/sec below 13 kilometers, or about 1 m/sec above 13 kilometers, and are possibly somewhat smaller than these values. These error values are substantially larger than those given by the implied theoretical values of equations (1) and (2), but the differences are not surprising when the possible overestimations of the empirical values and the idealized simplifying assumptions used in the theoretical calculations are considered. The error values in table III indicate a larger rms error for the False Cape – Williams Point camera pair compared with the Williams Point – Patrick pair, in contrast to the simplified theory which gives a larger value for the Williams Point – Patrick pair. The complete error equations in reference 1 indicate a larger effect of trail slope

for the False Cape — Williams Point pair; however, some of the difference may also be due to lens distortion or camera orientation error. Even the upper limits of errors are substantially smaller than those of conventional balloon systems (ref. 15).

Choice of Time Interval

The choice of a 1-minute time interval was based on previous experience at Wallops Island. Data presented in appendix B indicate that this interval is also appropriate for the Eastern Test Range, but that a 30-second interval is also acceptable if the earliest possible 30 seconds is used.

Representativeness

Experiments at Wallops Island (refs. 11, 12, and 14) involving multiple trails indicate that differences in velocities between trails over distances of several kilometers or time intervals of several minutes are no greater than measurement errors. It is believed that this degree of representativeness also applies to the Cape Kennedy area.

DISCUSSION OF RESULTS

Detailed plots of west-to-east and south-to-north components of wind velocity as a function of altitude are shown in figures 2 to 26. Wind-velocity values are computed for every 25-meter altitude increment and connected with straight line segments giving the appearance, on the scale used, of a continuous curve. The data contained in these figures are summarized in table I which shows the figure number, Langley identification number, date and time of launching, altitude range covered, and the maximum west-to-east velocity component. The trails are arranged in order of the Langley identification number and are in chronological order except for the first and last trails in the table.

The wind-velocity data presented in figures 2 to 26, together with wind speed and direction and wind-shear values, are available on request from the NASA Langley Research Center on punched cards or in tabular form as a supplement to this report.[*] The format and units of these data are illustrated by the sample tabulation in table II. Each profile is identified by a trail number, date and time of launch, altitude increment used in computation, time increments over which the data were taken, and camera and picture (frame) identification.

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[*]Requests should be directed to the NASA Langley Research Center and the paper should be cited by author, title, and code number. The specific profiles desired should be indicated.

The various measures of the wind shear, or rate of change of wind velocity with height, are evaluated over a height interval of 25 meters and apply to the 25-meter height interval immediately below the reported height. These wind-shear values have been included in the tabulation because of numerous requests. However, the user should be aware of the large errors involved in computation of shears over an interval as small as 25 meters. For example, an rms velocity error of 1.0 m/sec would result in an rms shear error of 0.056 sec^{-1}. (Actual shear values as large as 0.056 sec^{-1} are seldom encountered.) Of course, the magnitude of the error decreases in proportion to the altitude interval used; thus, some users may find it desirable to average several of the reported values or to compute directly the shears over larger altitude intervals.

The first measurement was made in August, but most of the measurements were made in October, November, and December. The maximum west-to-east component of 63 m/sec in trail 316 (fig. 16) exceeds the 95 percent highest component for the year (the value which will not be exceeded 95 percent of the time) and also the 95 percent highest for the month of December based on data from reference 16. Four of the profiles exceed the 90-percent value on an annual basis. Most of the profiles show relatively light winds at all altitudes but show double or multiple wind peaks in the region of 9 to 14 kilometers. Although the smoke-trail technique is limited to days with good visibility, the profiles in this report appear to be fairly typical for this season of the year.

For those who wish to make meteorological studies, radiosonde runs were made within 6 hours of each launch. These and other radiosonde data are available from the National Weather Records Center, U.S. Weather Bureau, Federal Building, Asheville, North Carolina.

Two of the profiles, 319 and 325 (figs. 19 and 25), show a number of unusually sharp spikes with exceptionally high negative shears in the top portion of the spikes. Caution should be exercised in the interpretation of these spikes, since in both cases it was necessary to use the False Cape — Williams Point camera pair; in some other cases where both camera pairs could be used, similar spikes appeared in profiles from the False Cape — Williams Point camera pair but did not appear in profiles from the Williams Point — Patrick pair. As shown in appendix B, the accuracy of the False Cape — Williams Point pair is poorer than that of the Williams Point — Patrick pair.

CONCLUDING REMARKS

Twenty-five detailed wind profiles measured by the smoke-trail technique at Cape Kennedy during the year 1962 are presented. The profiles included west-to-east and south-to-north components determined at 25-meter altitude increments. The altitude ranges of the individual profiles vary, but the overall range is approximately 2 to

21 kilometers. The wind profiles include a variety of conditions and include velocities in excess of the annual 95-percent extreme value. Most profiles have low to moderate peak values but exhibit considerable small scale variation. The accuracy of the profiles is approximately 0.5 m/sec for one camera pair and 1.0 m/sec for the other camera pair. This degree of detail and accuracy is substantially greater than that of data obtained with present-day conventional measuring systems.

Langley Research Center,
    National Aeronautics and Space Administration,
        Langley Station, Hampton, Va., October 12, 1965.

APPENDIX A

MACHINE DATA PROCESSING

By Mickey G. Rowe
Langley Research Center

Figure 27 is a simplified flow diagram of the data reduction procedures used in reducing the smoke-trail wind-shear and velocity data.

The data-processing personnel enter the sequence of events at step A. This step is a preliminary editing procedure designed to eliminate incorrectly punched cards and discrepancies which would halt the electronic data-processing system because of programer checks. The data-processing operator insures that the proper constants are available, arranges the punched cards in the proper order, performs hand editing as indicated on log sheets provided with the punched cards, and uses a collator to check the sequence of the cards and check the cards for double punches or blank columns.

An IBM 1401 electronic data-processing system is then used in step B to list the edited punched cards, prepare a data tape for processing by the IBM 7070 electronic data-processing system, and prepare a tape for a magnetic-tape plotter. As a quality control measure, the results on the tape are plotted and these plots and a listing of the raw data are returned to the project engineer for checking and editing. As a routine check, each picture of data is read twice on the comparator. Using the plots and the listing, the engineer checks the duplicate readings for similarity and checks successive pictures for continuity with increasing time. At this point the engineer can accept all readings for processing, select certain readings for processing, or direct that all or certain frames be reread for the smoke trail. Steps A and B can then be repeated as necessary.

At step C the data are actually reduced to final answers. Because of the magnetic-tape sort techniques utilized and system core storage limitations, there are six different programs involved in step C. However, the programs may be sequentially loaded with a minimum of operator intervention, each phase being executed as soon as the previous phase is completed. Naturally, if only certain phases are desired, they may be executed individually. The minor operational difficulties resulting from the phasing of the programs are offset by the ease with which intermediate answers can be printed and/or plotted as a quality control measure or as a check on the calculations. Of course, feasible programed checks are included in the system programs to insure that the electronic data-processing system is using the correct constants, that the data have been properly edited, and that the frame and camera numbers are being used in the correct sequence.

APPENDIX A

Both the input to and the output of step C are saved for storage to provide a rerun capability in the event of constant changes and to keep the answers available for further use without reprocessing.

Step D serves as an output function. Two special output tapes are prepared — a print tape for the IBM 1401 electronic data-processing system and a plot tape for the magnetic-tape plotter. These tapes are printed and plotted and the results are returned to the project engineer.

APPENDIX B

ACCURACY OF DATA

Empirical Error Estimates

Comparison of data from different base lines.- As described previously, the Cape Kennedy smoke-trail camera network contains two distinct camera pairs with different base lines. This arrangement offers a more extensive check than is available with a single base line, since the computations of wind profiles from the two camera pairs are completely independent. In most instances, unfavorable weather conditions precluded photography of the complete trail from all camera sites. For several cases where all three sites were operational, rms differences of the velocities for 60-second intervals were computed by using the two different camera pairs. These rms differences are shown in table IV. Mean differences were also computed, but were negligible and are not included in the tables. If it were assumed that the errors from the two camera pairs were equal, the rms error of each would be $1/\sqrt{2}$ or about 0.7 times the figures given in table IV. However, because of the unfavorable geometry of the False Cape — Williams Point pair, it is believed that the major contribution to the rms differences in table IV arises from errors in the False Cape — Williams Point data, and that errors in the Williams Point — Patrick data are substantially smaller, especially at the higher altitudes.

Reading errors.- Although it is not possible to isolate the contributions of the two separate camera pairs to the total rms differences, it is possible to compute the rms differences due to pure reading error separately for the two camera pairs. For several profiles, the rms differences between wind velocities calculated from the selected readings and wind velocities calculated from the rejected readings were determined. These rms differences for 60-second intervals are shown in table V. Although the errors in the rejected readings may be somewhat larger than the errors in the selected readings, in the cases shown in table V there were no large obvious errors in the rejected data, and it appears that $1/\sqrt{2}$ times these rms differences is a reasonably accurate estimate of the pure reading errors in data from the two camera pairs.

Limiting values of rms errors.- Average values of the vector rms differences from tables IV and V are shown in table VI, grouped by camera pair and altitude range. These values were based on unedited data and, in some cases, indicated excessive errors in the highest or lowest altitude range because of large errors in one of the profiles which were later edited out. Therefore, an additional column has been included showing averages of only those altitude ranges from each trail where there were no substantial deletions in the final editing process. From the data in table VI, it is possible to estimate some limits on the rms vector wind errors for the 60-second intervals.

First, it is obvious that the total error cannot be less than the pure reading error, so this reading error will set a lower limit. Thus, the rms reading error, calculated as

$1/\sqrt{2}$ times the rms difference, is entered in table III as the lower limit for each camera pair. Next, it was indicated that the contribution of errors for the Williams Point — Patrick camera pair to the total rms difference is expected to be less than the contribution from the error for the False Cape — Williams Point camera pair, and this expectation is verified by the reading error values for the two camera pairs. Thus, the error which would exist if the two contributions were equal establishes an upper limit for the rms errors of the Williams Point — Patrick camera pair. These values, computed as $1/\sqrt{2}$ times the rms differences between values from the two different base lines, are entered in table III as the upper limit for the Williams Point — Patrick camera pair.

Finally, although the contribution of the rms error for the False Cape — Williams Point camera pair is expected to be greater than that of the Williams Point — Patrick pair, it must be less than the total rms difference. Thus, the total rms difference establishes an upper limit for the rms vector error of the False Cape — Williams Point camera pair. These differences are entered as the upper limits of the rms errors for the False Cape — Williams Point pair in table III.

In interpreting these rms values, it should be noted that winds at the same computed altitude were compared and that the computed altitudes may be in error by about 100 meters at the higher altitudes. Thus, for regions of high shear, a large rms error may be reported simply as a result of a small vertical displacement of one of the wind profiles; however, this type of error would not be of importance for most uses of the data. Errors of this type are not included in the theoretical error values of equations (1) and (2) in the present report, nor in the complete error equations in reference 1.

The values in table VI indicate that the rms vector errors of the wind profiles in this report will lie somewhere between about 1/10 m/sec and about 1 m/sec, and will depend on the camera pair used and the altitude range. For example, for the Williams Point — Patrick pair below 13 kilometers, the rms vector error will be below 1/2 m/sec. On the other hand, the rms error for the False Cape — Williams Point pair above 13 kilometers will be about 1 m/sec.

Since the errors for the False Cape — Williams Point pair are not only larger but also increase more rapidly with altitude, the Williams Point — Patrick pair is used whenever possible.

Effect of Time Interval

For structural dynamic studies, it is desirable to have as near an instantaneous measurement of the wind as possible. On the other hand, for a given error in trail position, the velocity error varies inversely with the time interval used, and errors become quite large for very small time intervals. The choice of a 1-minute time interval

was based on earlier experience with Wallops Island data (refs. 1 and 12). In order to examine the effect of the length of time over which the measurements are averaged on accuracy of wind measurements at the Cape Kennedy camera network, which differs in some respects from that at Wallops Island, rms differences were calculated for the first 30-second interval and the last 30-second interval of the 60-second intervals of tables III and IV.

These rms differences are presented along with the rms differences for the 60-second intervals in table VII. Because the final editing process for the 60-second profiles makes use of the two constituent 30-second intervals, it is not feasible to duplicate this editing process for the 30-second profiles. Unedited values were used for the 60-second profiles so they would be comparable to the 30-second profiles. Only altitude ranges of 5 to 9 kilometers and 9 to 13 kilometers, where relatively little editing is required, are shown. Although no conclusions are drawn as to the exact values of error represented by these unedited data, it is expected that relative magnitudes of the rms errors would be similar to the relative magnitudes of the rms differences. The data in table VII indicate that the 60-second interval yields greater accuracy than the 30-second interval, but that the 30-second profile accuracy would be acceptable, especially if the first 30-second interval is used. The substantial increase in rms differences between the first and last 30-second interval shows the effect of increasing distortion irregularity of the trail with time. This increase suggests that little if any accuracy would be gained by using time intervals longer than 1 minute.

REFERENCES

1. Henry, Robert M.; Brandon, George W.; Tolefson, Harold B.; and Lanford, Wade E.: The Smoke-Trail Method for Obtaining Detailed Measurements of the Vertical Wind Profile for Application to Missile-Dynamic-Response Problems. NASA TN D-976, 1961.

2. Murrow, Harold N.; and Henry, Robert M.: Self-Induced Balloon Motions. J. Appl. Meteorol., vol. 4, no. 1, Feb. 1965, pp. 131-138.

3. Tolefson, Harold B.; and Henry, Robert M.: A Method of Obtaining Detailed Wind Shear Measurements for Application to Dynamic Response Problems of Missile Systems. J. Geophys. Res., vol. 66, no. 9, Sept. 1961, pp. 2849-2862.

4. Henry, Robert M.; and Brandon, George W., Jr.: The Use of Smoke Trails as Wind Sensors. 1961 Proceedings ISA 16th Annual Instrument-Automation Conference and Exhibit, vol. 16-pt. 2-b, 1961, pp. 174-LA-61-1 – 174-LA-61-16.

5. Tolefson, Harold B.: Smoke-Trail Measurements of the Vertical Wind Profile and Some Applications. Air Force Surv. in Geophys. No. 140 (AFCRL-62-273(I)), Air Force Cambridge Res. Center, Mar. 1962.

6. Morgan, Homer G.; and Baron, Sheldon: Wind Loads on a Vertically Rising Vehicle Including Effects of Time-Varying Parameters. Structural Dynamics of High Speed Flight, ACR-62, vol. 1, Office of Naval Res., Apr. 1961, pp. 413-446.

7. Baron, Sheldon: Analysis of a Vertically Rising Vehicle. M. A. Thesis, The College of William and Mary, 1961.

8. Morgan, Homer G.; and Collins, Dennis F., Jr.: Some Applications of Detailed Wind Profile Data to Launch Vehicle Response Problems. AIAA J., vol. 1, no. 2, Feb. 1963, pp. 368-373.

9. Scoggins, James R.: High Resolution Wind Measurement: A Launch Design Problem. Astronaut. Aerospace Eng., vol. 1, no. 3, Apr. 1963, pp. 106-107.

10. Lester, Harold C.; and Morgan, Homer G.: Determination of Launch-Vehicle Response to Detailed Wind Profiles. Preprint No. 64-82, Am. Inst. Aeron. Astronaut., Jan. 1964.

11. Lester, Harold C.; and Tolefson, Harold B.: A Study of Launch-Vehicle Responses to Detailed Characteristics of the Wind Profile. J. Appl. Meteorol., vol. 3, no. 5, Oct. 1964, pp. 491-498.

12. Miller, Robert W.; Henry, Robert M.; and Rowe, Mickey G.: Wind Velocity Profiles Measured by the Smoke-Trail Method at Wallops Island, Virginia, 1959 to 1962. NASA TN D-2937, 1965.

13. Lanford, Wade E.; Perry, Tom W., Jr.; Baber, Hal T., Jr.; and Booth, Franklin W.: Development of a Smoke-Trail Vehicle for Application to Wind-Shear Measurements up to 80,000 Feet. NASA TN D-2009, 1963.

14. Lanford, Wade E.; Janos, Joseph, J.; and Baber, Hal T., Jr.: Comparison and Evaluation of Several Chemicals as Agents for Rocket-Vehicle Production of Smoke Trails for Wind-Shear Measurements. NASA TN D-2277, 1964.

15. Tolefson, Harold B.: An Investigation of Vertical-Wind-Shear Intensities From Balloon Soundings for Application to Airplane- and Missile-Response Problems. NACA TN 3732, 1956.

16. Anon.: Atlantic Missile Range Reference Atmosphere for Cape Kennedy, Florida (Part I). IRIG Doc. 104-63, Range Commanders Council, April 16, 1963.

TABLE I

EASTERN TEST RANGE WIND PROFILES FOR 1962 LAUNCHINGS

Figure	Trail identification	Date	EST	Altitude range, km	Maximum west-to-east component of velocity, m/sec	Remarks (a)
2	302	10/03/62	1530	3.8 to 15.4	16	
3	303	8/08/62	1215	4.6 to 16.2	-12	FC
4	304	9/25/62	1528	3.3 to 11.4	17[b]	
5	305	10/08/62	1300	4.2 to 16.4	14	
6	306	10/10/62	1530	4.6 to 16.5	22	
7	307	10/19/62	1453	4.8 to 13.0	13[b]	
8	308	10/29/62	1513	5.1 to 13.2	23[b]	
9	309	11/01/62	1502	3.9 to 15.8	22	FC
10	310	11/05/62	1603	4.7 to 20.9	37	
11	311	11/06/62	1549	4.2 to 16.2	55	FC
12	312	11/13/62	1430	5.2 to 15.4	28	
13	313	11/16/62	1523	3.7 to 17.8	34	FC
14	314	12/04/62	1507	3.0 to 15.9	50	FC
15	315	12/06/62	1620	5.0 to 14.2	57[b]	FC
16	316	12/10/62	1230	4.2 to 16.2	63	
17	317	12/11/62	1547	3.8 to 14.0	44[b]	
18	318	12/13/62	1500	3.2 to 19.0	54	
19	319	12/14/62	1436	2.3 to 17.8	52	FC
20	320	12/17/62	1526	3.8 to 16.6	15	
21	321	12/18/62	1203	3.2 to 14.4	23	
22	322	12/19/62	1200	4.5 to 18.2	29	
23	323	12/20/62	1447	3.7 to 16.0	25	
24	324	12/21/62	1226	4.2 to 15.0	41	FC
25	325	12/28/62	1307	3.6 to 21.4	47	FC
26	368	11/16/62	1245	11.4 to 18.1	29	Saturn SA-3

[a]FC signifies that False Cape — Williams Point camera pair was used.

[b]Higher wind may have occurred above altitude range measured.

TABLE II

SAMPLE TABULATION

Z (METERS)	VX (MPS)	VY (MPS)	V (MPS)	THETA (DEGREES)	SHEAR X (/SEC)	SHEAR Y (/SEC)	SHEAR V (/SEC)	SHEAR M (/SEC)
12175	31.8	5.3	32.24	260.91	.008	.008	.011	.009
12200	32.2	4.3	32.49	262.59	.016	−.040	.043	.010
12225	32.6	3.3	32.77	264.29	.016	−.040	.043	.011
12250	33.2	3.4	33.37	264.29	.024	.004	.024	.024
12275	33.4	3.2	33.55	264.86	.008	−.008	.011	.007
12300	33.3	3.0	33.43	264.86	−.004	−.008	.008	.004
12325	33.3	3.1	33.44	264.86	.000	.004	.003	.000
12350	33.3	3.5	33.48	264.29	.000	.016	.016	.001
12375	33.2	3.9	33.43	263.72	−.004	.016	.016	.002
12400	33.1	4.1	33.35	263.15	−.004	.008	.008	.003
12425	32.9	3.9	33.13	263.72	−.008	−.008	.011	.008
12450	33.0	4.5	33.31	262.59	.004	.024	.024	.007
12475	33.2	5.2	33.60	261.46	.008	.028	.029	.011
12500	33.5	5.5	33.95	260.91	.012	.012	.016	.014
12525	33.5	6.4	34.11	259.24	.000	.036	.035	.006
12550	33.1	6.5	33.73	259.24	−.016	.004	.016	.015
12575	33.2	6.5	33.83	259.24	.004	.000	.003	.004
12600	33.3	6.4	33.91	259.24	.004	−.004	.005	.003
12625	33.4	6.7	34.07	258.69	.004	.012	.012	.006
12650	33.4	7.1	34.15	258.14	.000	.016	.016	.003
12675	33.2	7.2	33.97	258.14	−.008	.004	.008	.007
12700	33.5	7.3	34.29	258.14	.012	.004	.012	.012
12725	34.0	7.3	34.77	258.14	.020	.000	.019	.019
12750	34.0	7.4	34.80	258.14	.000	.004	.003	.001
12775	34.1	7.6	34.94	257.59	.004	.008	.008	.005
12800	34.3	7.9	35.20	257.05	.008	.012	.014	.010
12825	34.8	7.8	35.66	257.59	.020	−.004	.020	.018
12850	35.4	7.1	36.10	258.69	.024	−.028	.036	.017
12875	35.5	7.3	36.24	258.69	.004	.008	.008	.005
12900	35.5	7.5	36.28	258.14	.000	.008	.007	.001
12925	35.3	7.1	36.01	258.69	−.008	−.016	.017	.010
12950	35.1	7.0	35.79	259.24	−.008	−.004	.008	.008
12975	34.8	6.8	35.46	259.24	−.012	−.008	.014	.013
13000	33.3	6.0	33.84	259.79	−.060	−.032	.068	.064
13025	33.4	6.2	33.97	259.79	.004	.008	.008	.005
13050	33.5	6.3	34.09	259.79	.004	.004	.005	.004
13075	32.9	6.3	33.50	259.24	−.024	.000	.024	.023
13100	32.6	6.3	33.20	259.24	−.012	.000	.012	.012
13125	32.5	6.3	33.10	259.24	−.004	.000	.003	.004
13150	32.4	6.4	33.03	259.24	−.004	.004	.005	.002
13175	32.0	6.3	32.61	259.24	−.016	−.004	.016	.016
13200	31.3	6.2	31.91	259.24	−.028	−.004	.028	.028
13225	31.2	6.3	31.83	258.69	−.004	.004	.005	.003
13250	30.7	6.3	31.34	258.69	−.020	.000	.019	.019
13275	30.7	6.7	31.42	258.14	.000	.016	.016	.003
13300	31.4	6.8	32.13	258.14	.028	.004	.028	.028
13325	31.2	7.2	32.02	257.05	−.008	.016	.017	.004
13350	31.2	7.7	32.14	256.50	.000	.020	.019	.004
13375	30.9	8.0	31.92	255.96	−.012	.012	.016	.008
13400	30.9	8.1	31.94	255.43	.000	.004	.003	.000

Z   altitude, meters

VX   west-to-east component of velocity, meters per second

VY   south-to-north component of velocity, meters per second

V   magnitude of resultant velocity, meters per second

Theta   direction from which wind is blowing, degrees

Shear X $\delta VX / \delta Z$, per second

Shear Y $\delta VY / \delta Z$, per second

Shear M $\delta V / \delta Z$, per second

Shear V $\sqrt{\left(\dfrac{\delta VX}{\delta Z}\right)^2 + \left(\dfrac{\delta VY}{\delta Z}\right)^2}$, per second

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TABLE III

APPROXIMATE UPPER AND LOWER LIMITS OF ROOT-MEAN-SQUARE

VECTOR ERRORS OF VELOCITY

[60-second time intervals]

Altitude range, km	Root-mean-square errors, m/sec	
	Williams Point – Patrick base line	False Cape – Williams Point base line
5 to 9	0.1 to 0.4	0.1 to 0.6
9 to 13	.2 to .4	.3 to .6
Above 13	.3 to .8	.8 to 1.1

TABLE IV

ROOT-MEAN-SQUARE VELOCITY DIFFERENCES BETWEEN WIND PROFILES

FROM CAMERA PAIRS ON DIFFERENT BASE LINES

[60-second time interval]

Altitude range, km	Root-mean-square differences		
	West-to-east component, m/sec	South-to-north component, m/sec	Vector, m/sec
Trail 302			
3.8 to 5.0	0.2	0.0	0.2
5.0 to 9.0	.6	.3	.6
9.0 to 13.0	.8	.5	.9
13.0 to 15.4	2.4	.8	2.6
3.8 to 15.4	1.2	.5	1.3
Trail 305			
4.2 to 5.0	0.4	0.2	0.5
5.0 to 9.0	.8	.3	.8
9.0 to 13.0	.6	.3	.7
13.0 to 13.9	.6	.6	.9
4.2 to 13.9	.7	.4	.8
Trail 308			
5.1 to 9.0	1.1	0.2	1.1
9.0 to 13.0	2.3	1.7	2.9
5.1 to 13.0	1.8	1.3	2.2
Trail 310			
4.7 to 5.0	0.1	0.0	0.1
5.0 to 9.0	.2	.1	.2
9.0 to 13.0	.9	.5	1.0
13.0 to 17.3	2.0	1.7	2.6
4.7 to 17.3	1.3	1.0	1.6
Trail 312			
5.4 to 9.0	0.6	0.3	0.7
9.0 to 13.0	.4	.2	.5
13.0 to 15.2	.9	.8	1.2
5.4 to 15.2	.6	.4	.8

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TABLE V

ROOT-MEAN-SQUARE VELOCITY DIFFERENCES BETWEEN WIND PROFILES FROM SELECTED AND REJECTED READINGS

[60-second time interval]

(a) Williams Point — Patrick base line

Altitude range, km	Root-mean-square velocity errors		
	West-to-east component, m/sec	South-to-north component, m/sec	Vector, m/sec
Trail 320			
3.7 to 5.0	0.1	0.0	0.1
5.0 to 9.0	.1	.0	.1
9.0 to 13.0	.1	.1	.1
13.0 to 16.6	.5	.6	.8
3.7 to 16.6	.3	.3	.5
Trail 321			
3.2 to 5.0	0.1	0.1	0.2
5.0 to 9.0	.0	.0	.0
9.0 to 13.0	.4	.3	.5
13.0 to 14.4	.1	.0	.1
3.2 to 14.4	.2	.2	.3
Trail 323			
3.6 to 5.0	1.3	0.2	1.3
5.0 to 9.0	.1	.1	.2
9.0 to 13.0	.2	.2	.3
13.0 to 16.6	.2	.2	.3
3.6 to 16.6	.5	.2	.5

TABLE V.- Concluded

ROOT-MEAN-SQUARE VELOCITY DIFFERENCES BETWEEN WIND PROFILES

FROM SELECTED AND REJECTED READINGS

[60-second time interval]

(b) False Cape — Williams Point base line

Altitude range, km	Root-mean-square velocity errors		
	West-to-east component, m/sec	South-to-north component, m/sec	Vector, m/sec
Trail 315			
5.0 to 9.0	0.0	0.1	0.1
9.0 to 13.0	.2	.2	.3
13.0 to 14.1	1.2	1.3	1.8
5.0 to 14.1	.4	.5	.7
Trail 324			
4.2 to 5.0	0.6	0.4	0.7
5.0 to 9.0	.1	.1	.1
9.0 to 13.0	.5	.2	.6
13.0 to 15.0	.3	.4	.5
4.2 to 15.0	.4	.2	.5

TABLE VI

ROOT-MEAN-SQUARE VECTOR DIFFERENCES OF VELOCITY

[60-second time interval]

Altitude range, km	Root-mean-square differences, m/sec			
	Williams Point – Patrick base line (unedited)	False Cape – Williams Point base line (unedited)	Different base lines	
			Unedited	Edited
5 to 9	0.1	0.1	0.7	0.6
9 to 13	.3	.5	1.0	.6
Above 13	.4	1.2	1.9	1.1

TABLE VII

COMPARISON OF 30-SECOND AND 60-SECOND ROOT-MEAN-SQUARE

VECTOR DIFFERENCES OF VELOCITY

Trail identification	Root-mean-square differences, m/sec					
	5 to 9 kilometers			9 to 13 kilometers		
	60 sec	First 30 sec	Last 30 sec	60 sec	First 30 sec	Last 30 sec
Different base lines						
308	1.1	2.3	2.0	2.9	1.7	5.9
310	.2	.3	.4	1.0	1.1	1.4
312	.7	.4	1.3	.5	1.7	.7
Average	.7	1.0	1.2	1.5	1.5	2.3
Same base lines						
315	0.1	0.2	0.3	0.3	0.3	0.7
320	.1	.2	.2	.1	.2	.3
321	.0	.2	.3	.5	.2	1.0
323	.2	.2	.4	.3	.5	.6
324	.1	.2	.3	.6	2.0	2.3
Average	.1	.2	.3	.4	.6	1.0
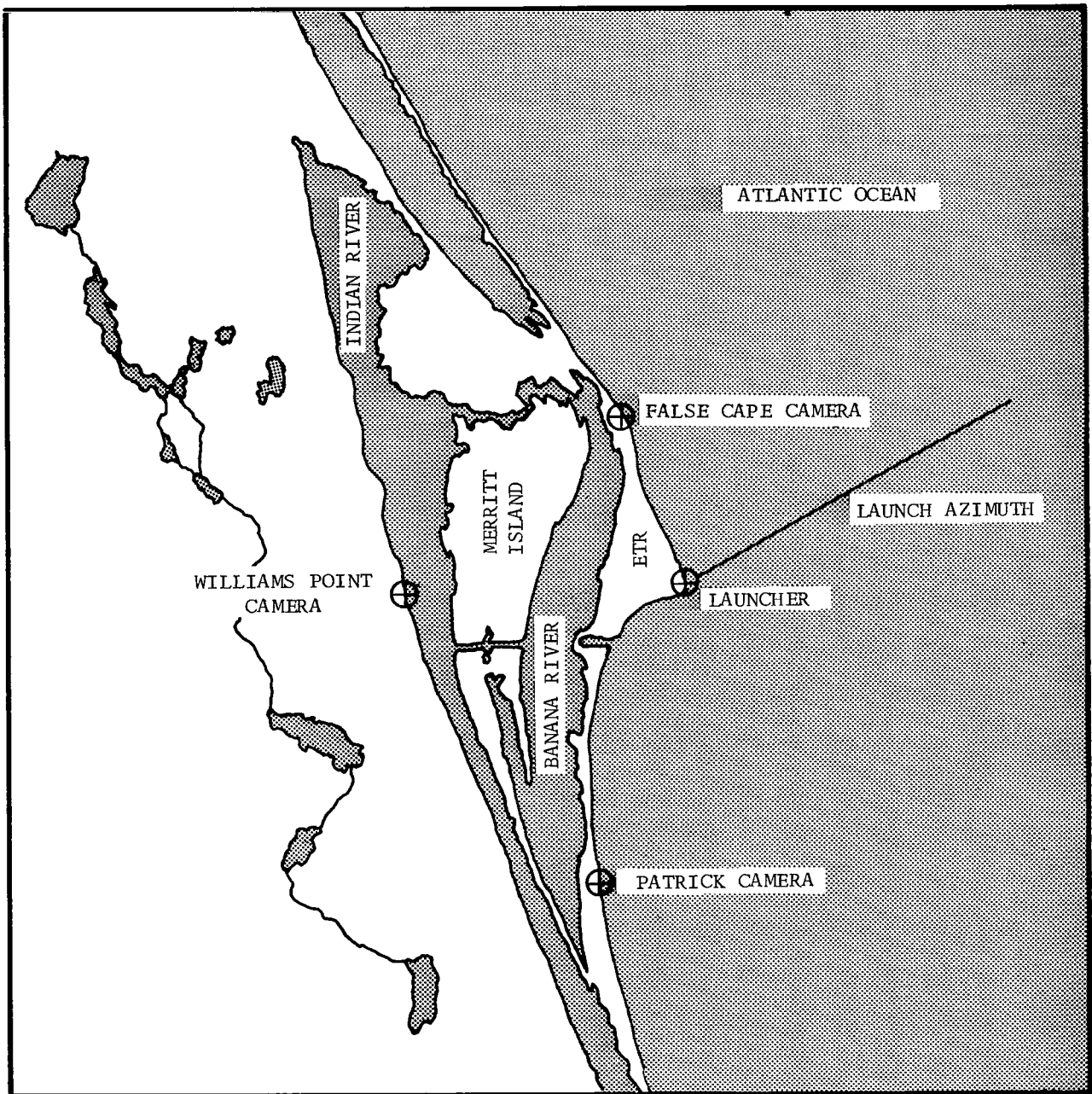
Figure 1.- The Eastern Test Range smoke-trail camera network.
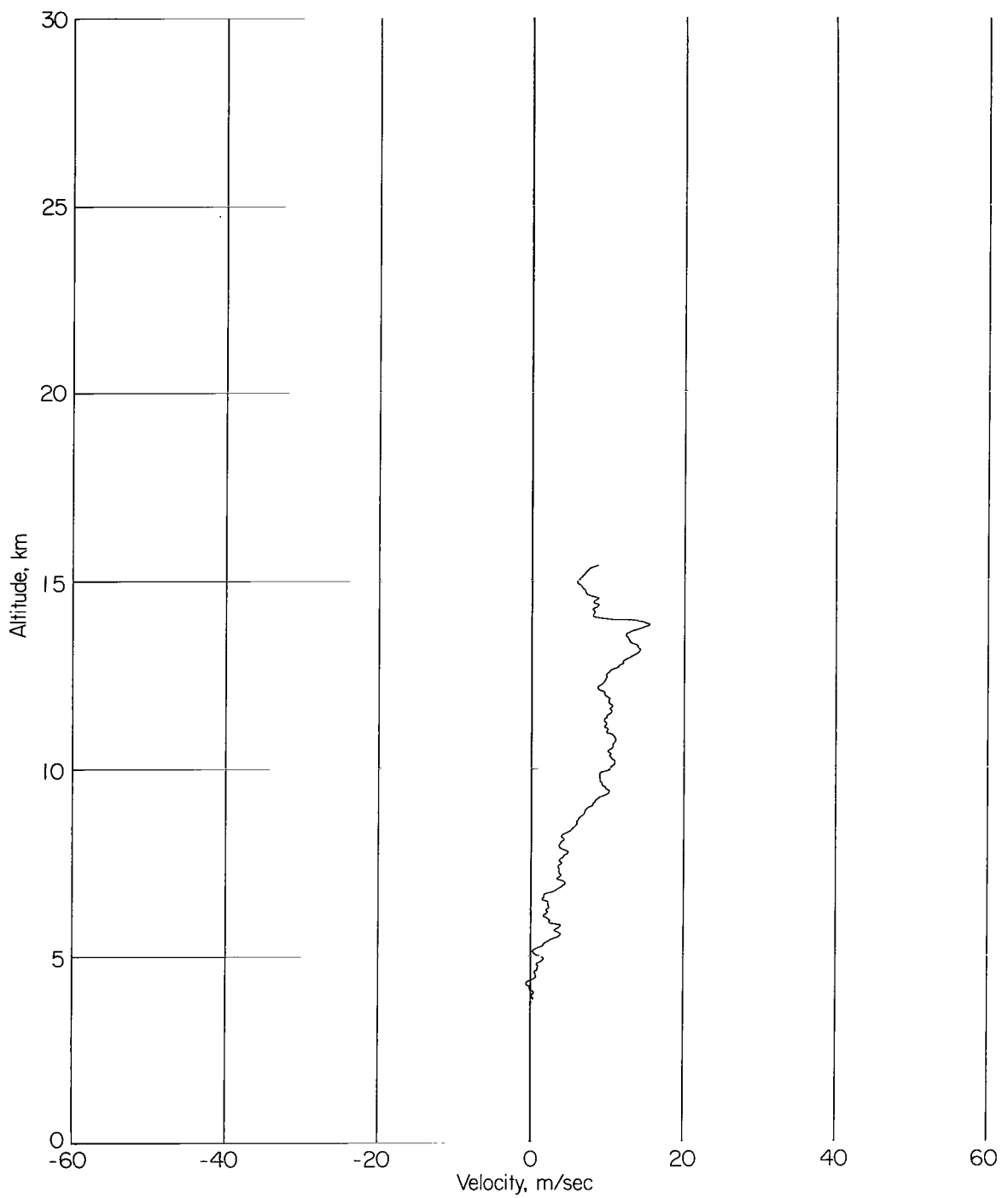
(a) West-to-east velocity component.

Figure 2.- Smoke-trail wind profile obtained on October 3, 1962. Trail 302; time interval of 60 seconds; height interval of 25 meters.
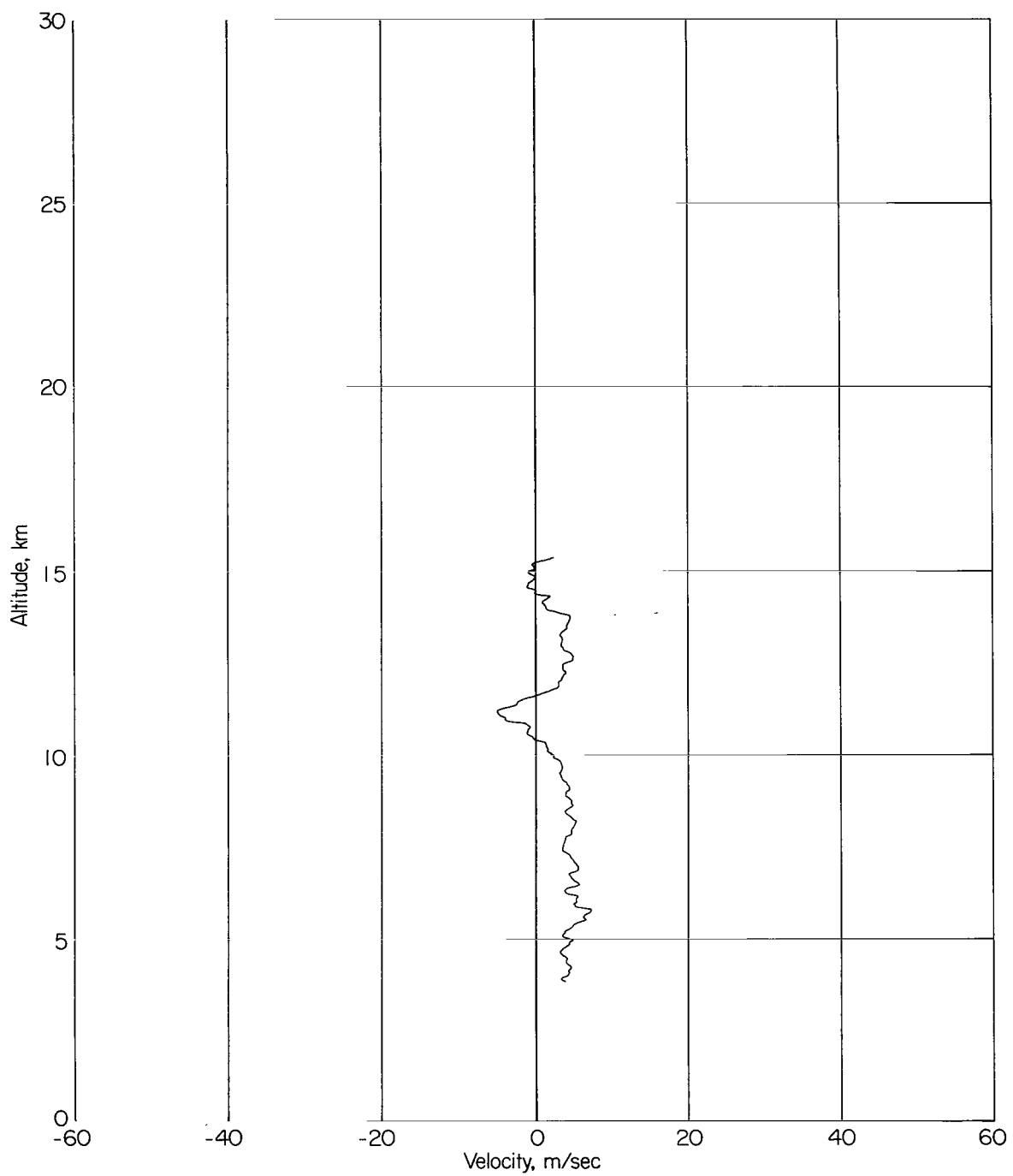
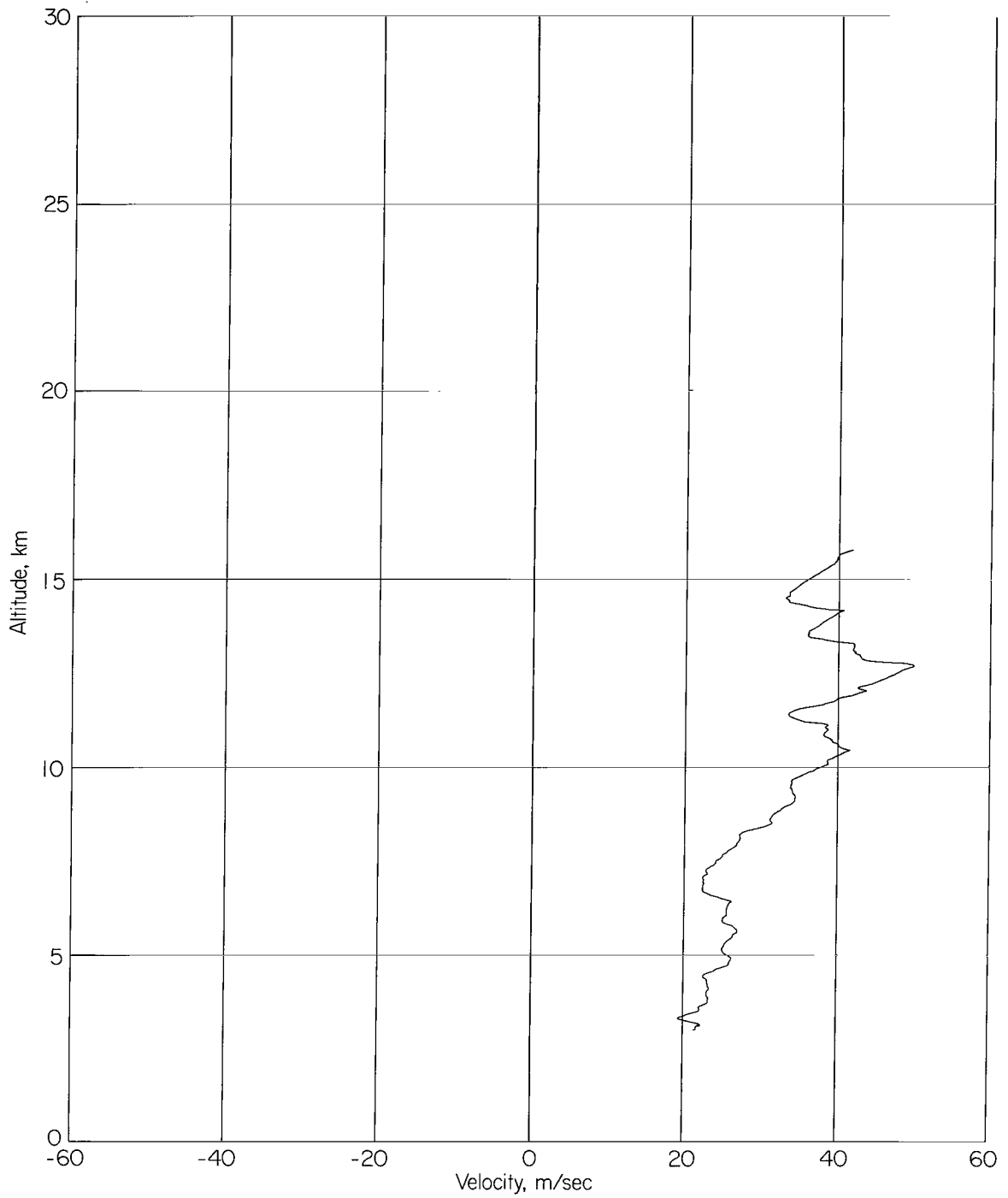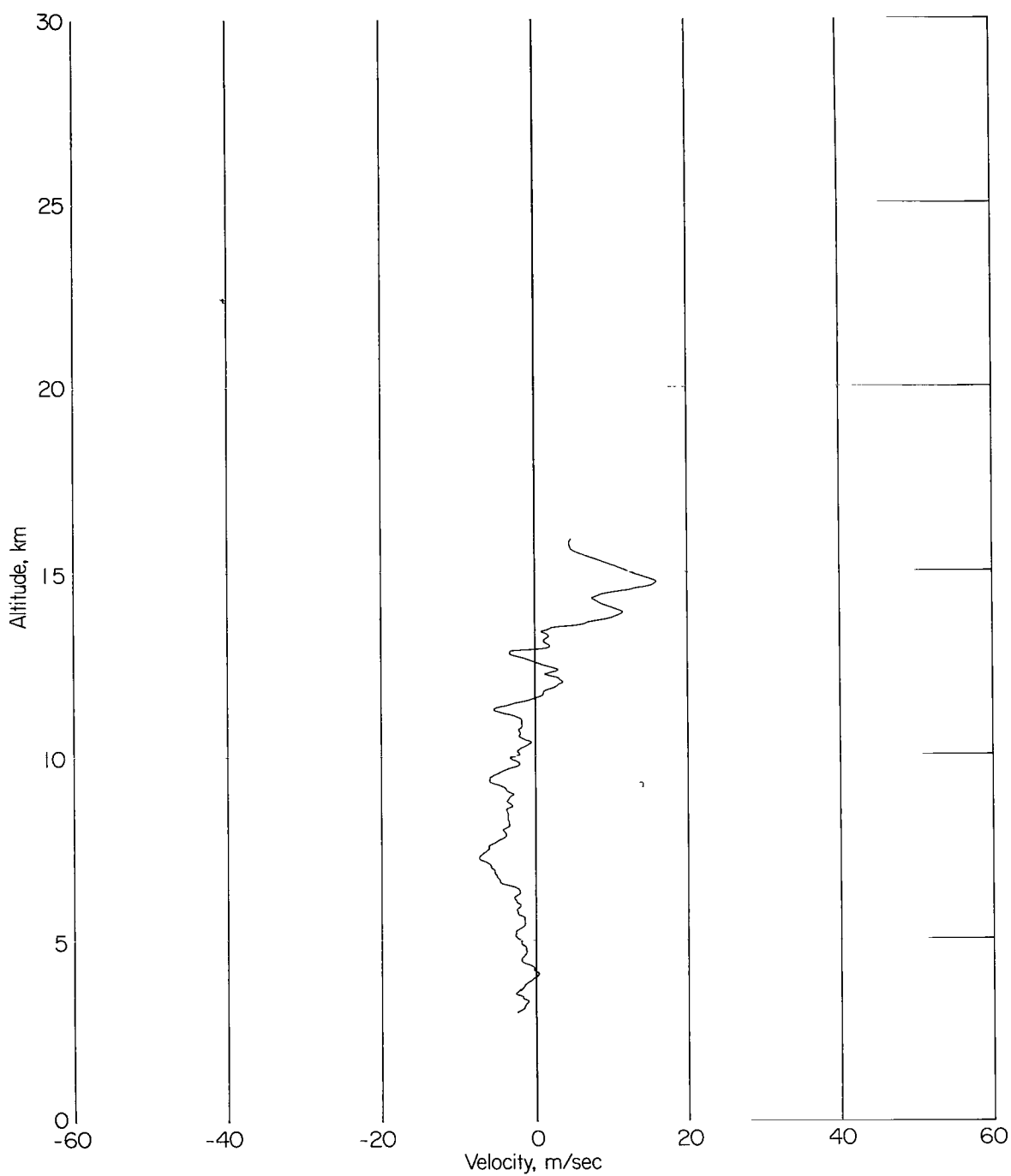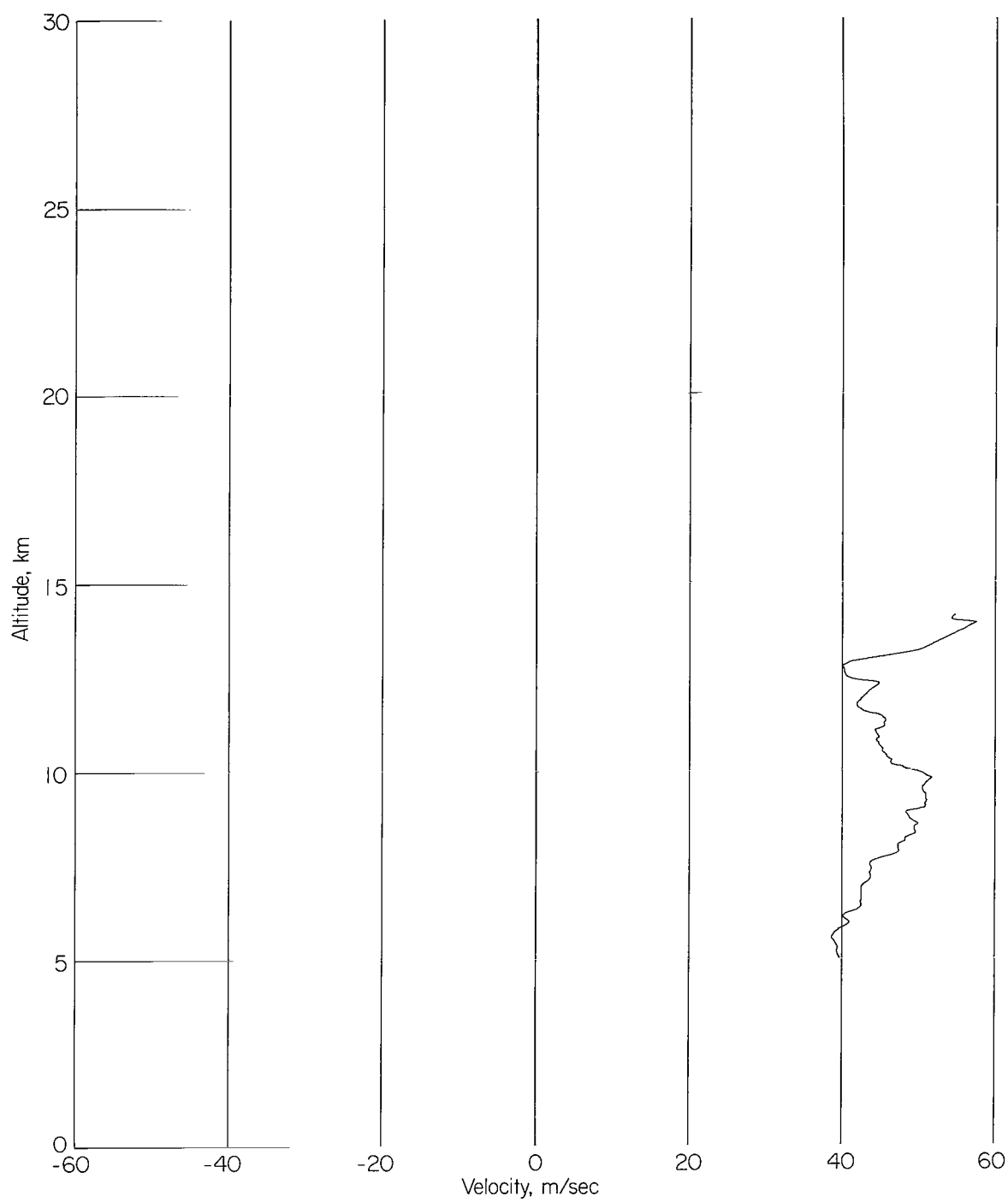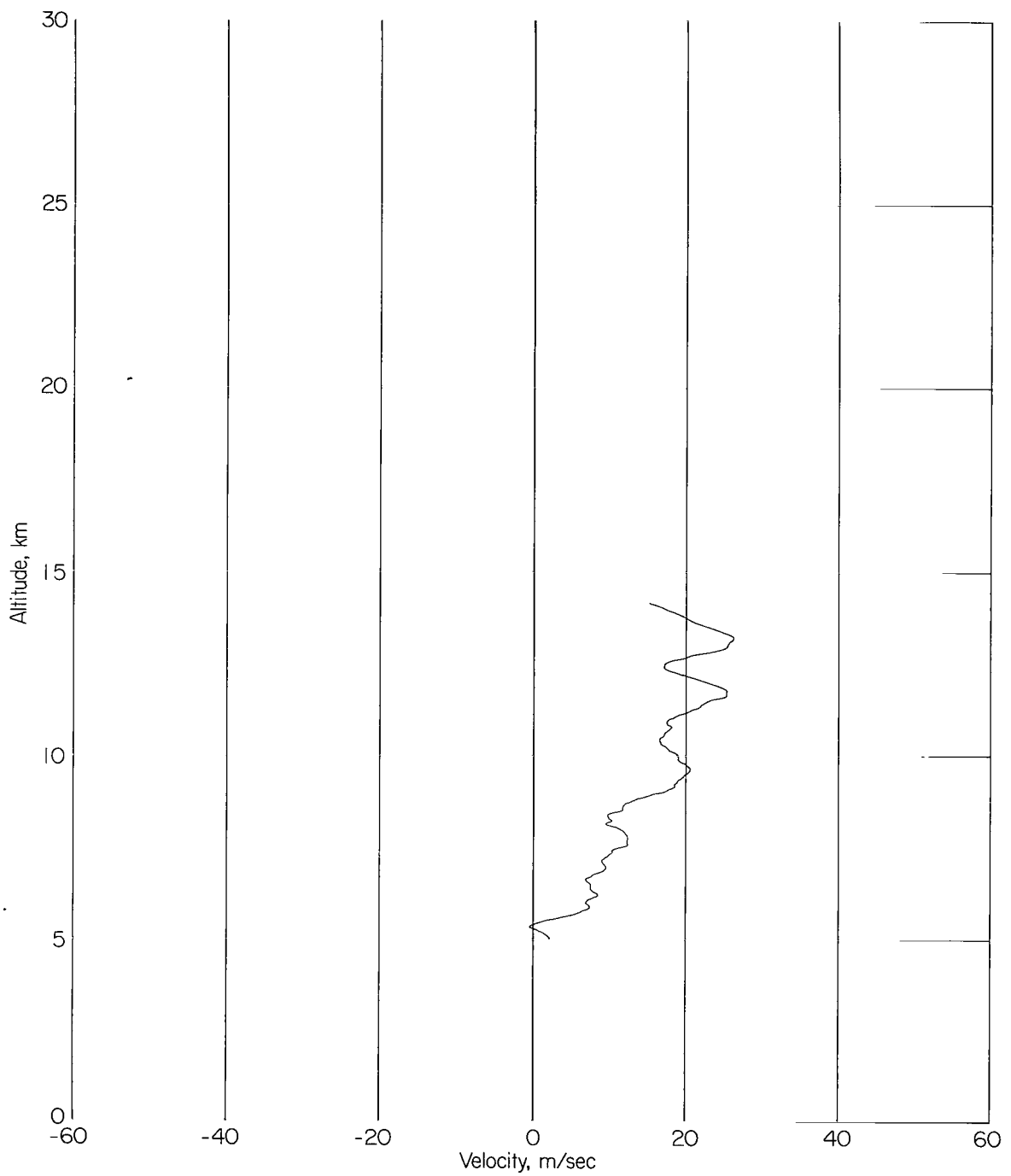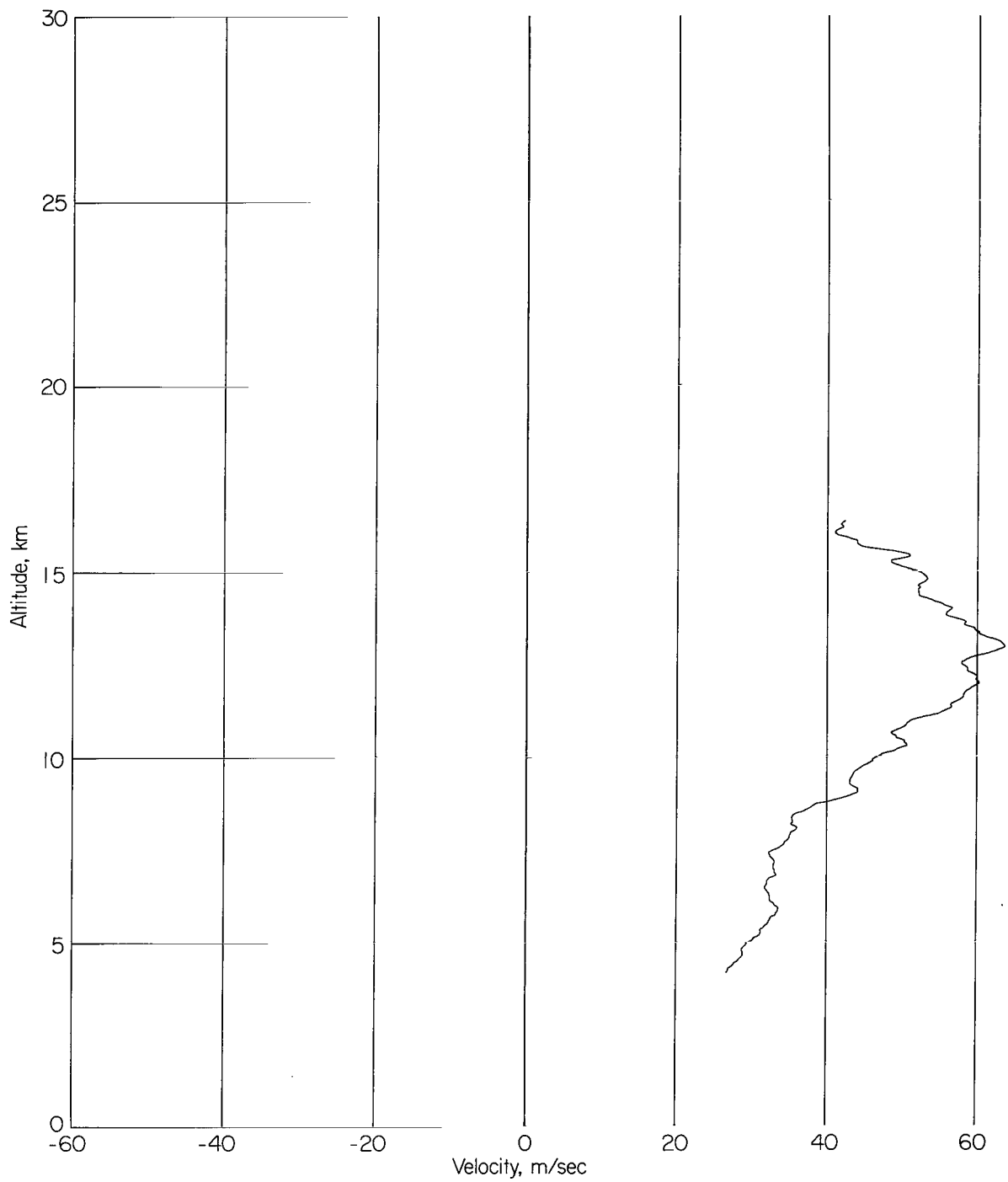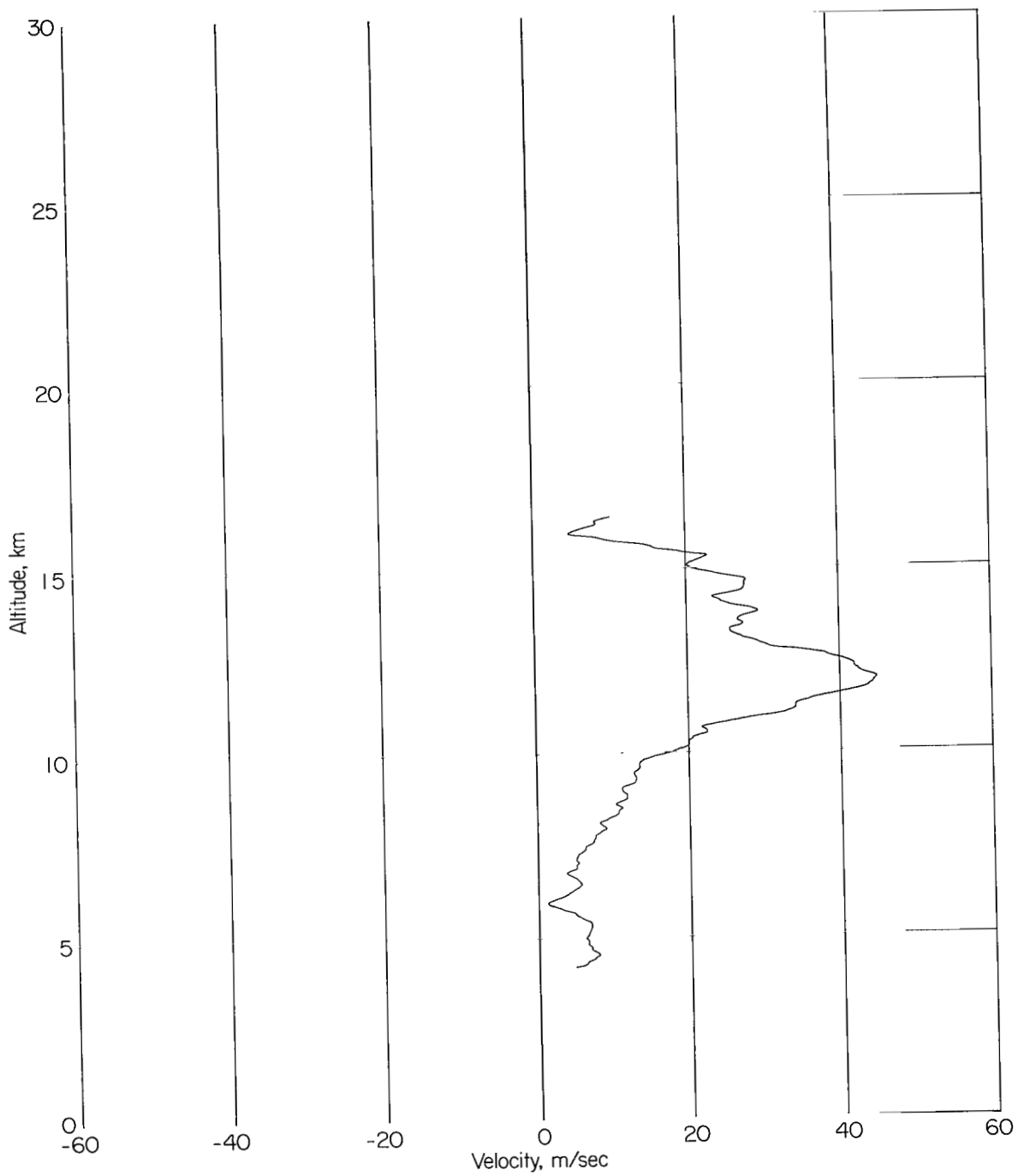(b) South-to-north velocity components.

Figure 2.- Concluded.
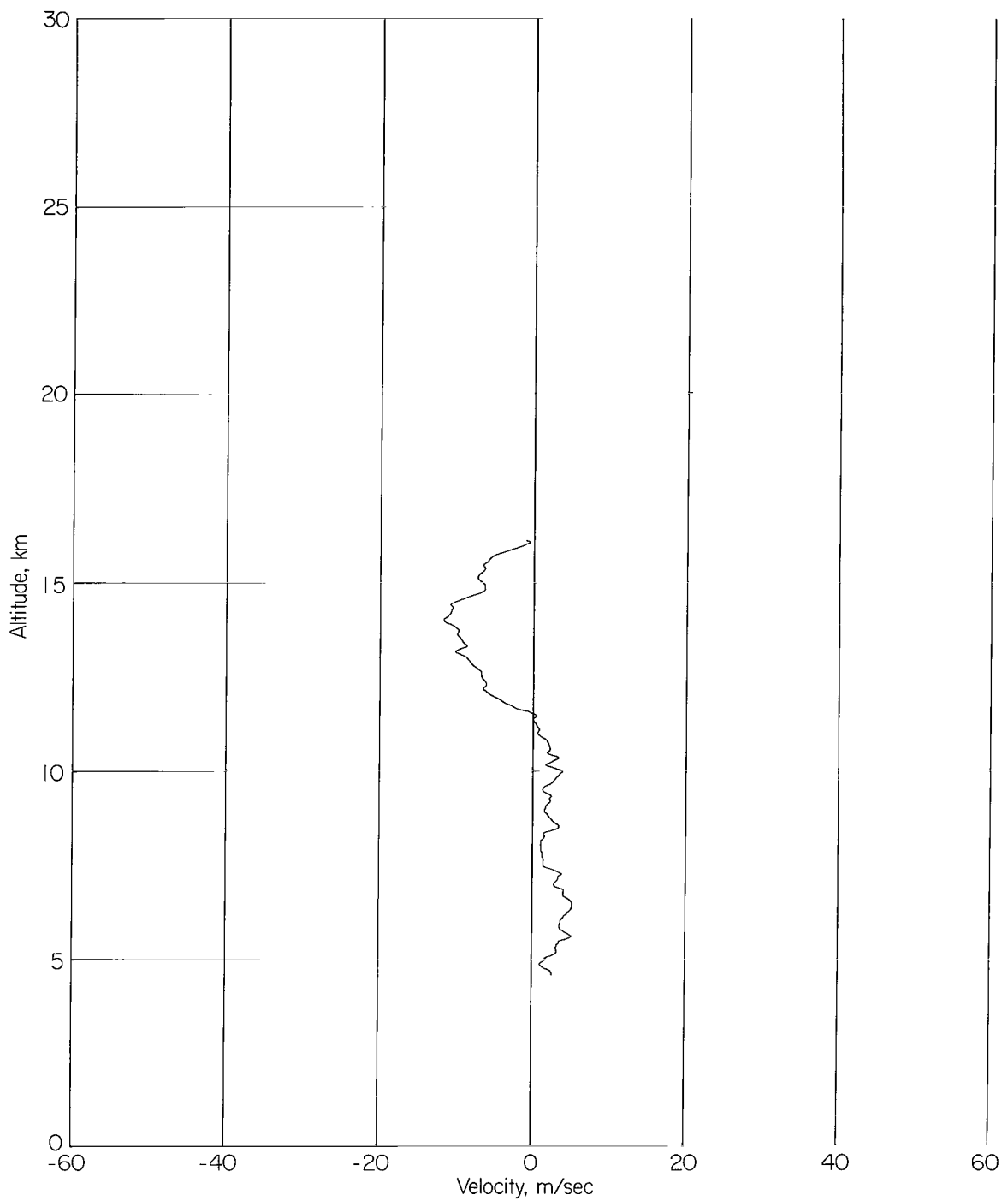
(a) West-to-east velocity component.

Figure 3.- Smoke-trail wind profile obtained on August 8, 1962. Trail 303; time interval of 60 seconds; height interval of 25 meters.
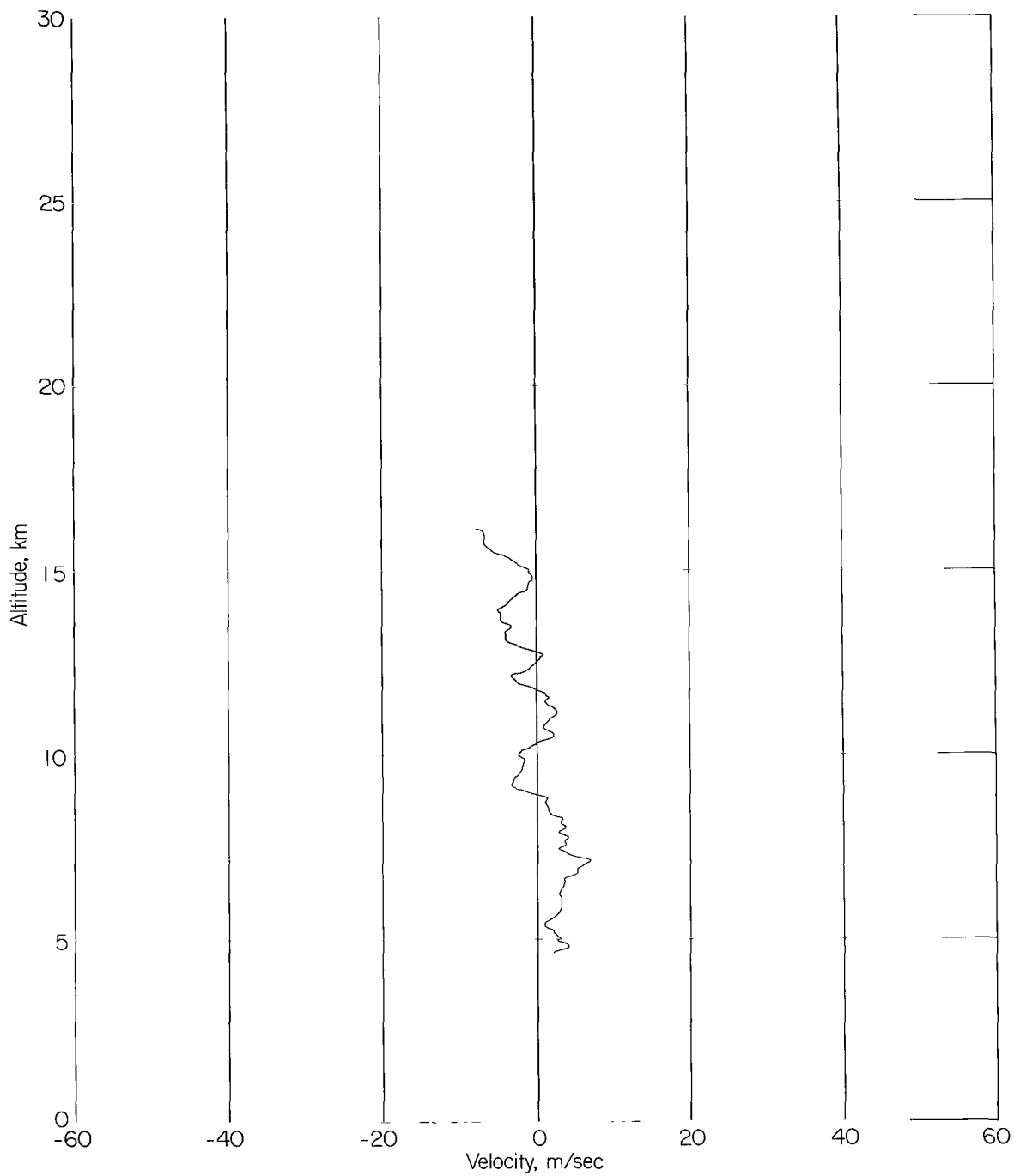
(b) South-to-north velocity component.
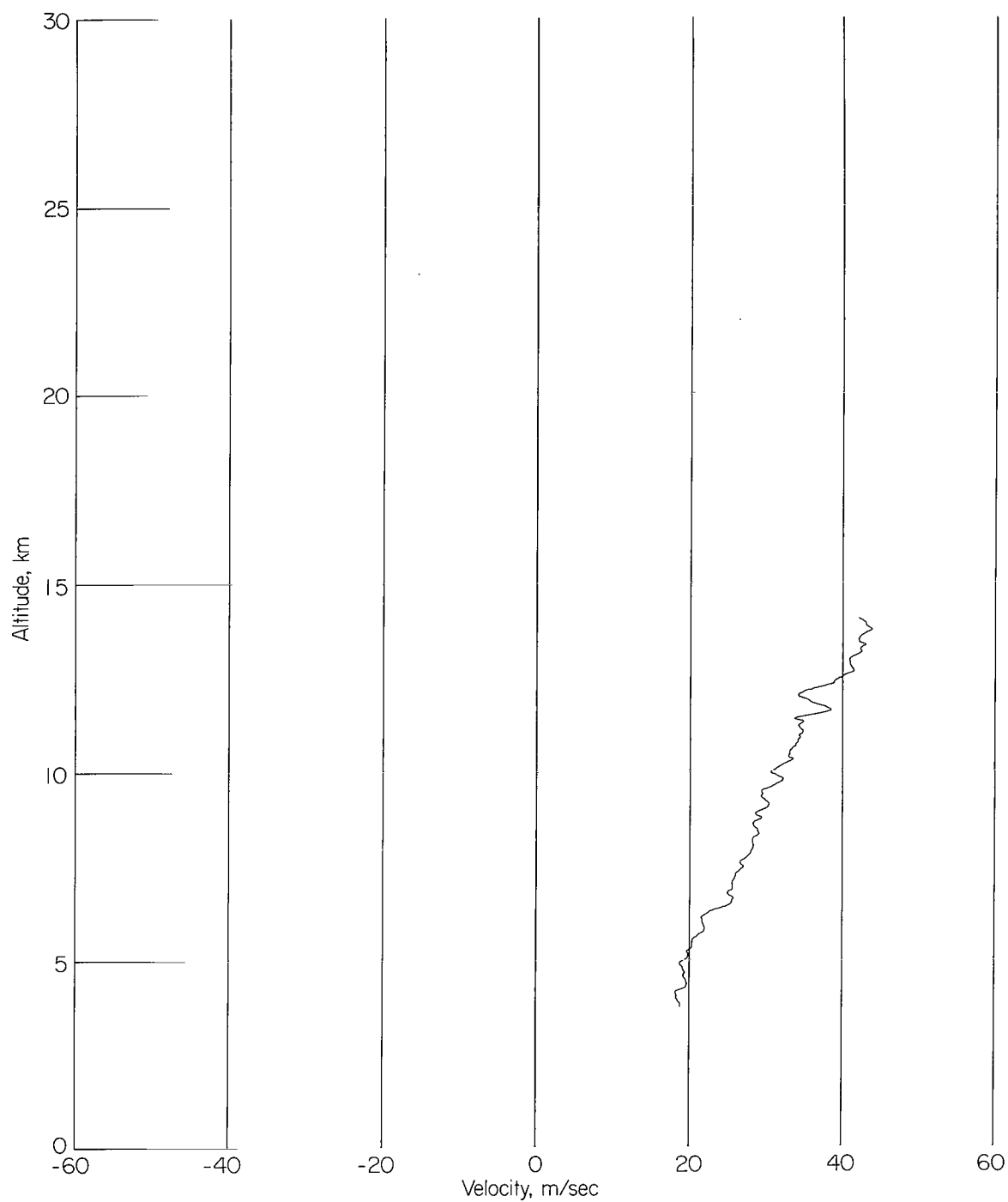
Figure 3.- Concluded.

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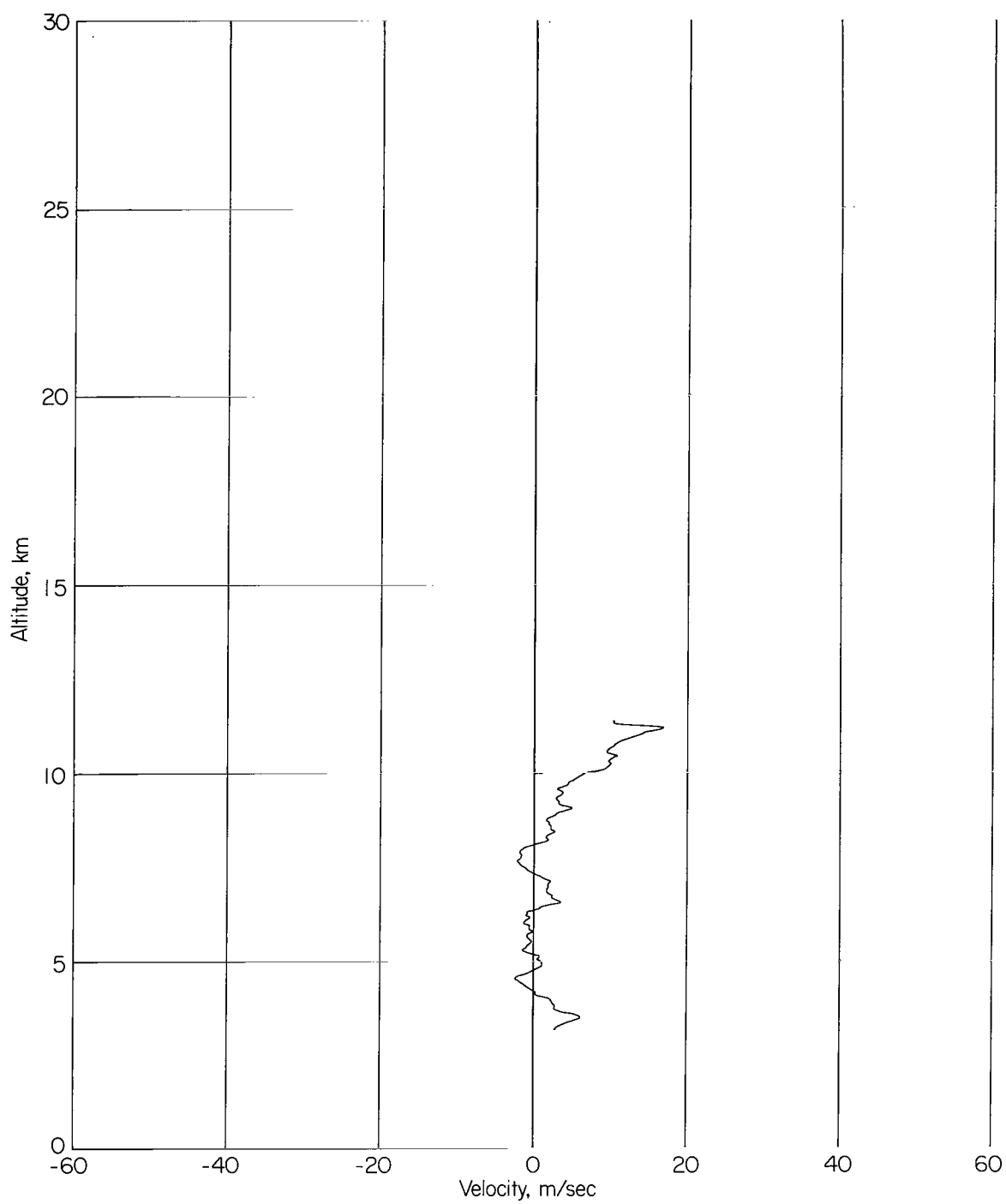
(a) West-to-east velocity component.

Figure 4.- Smoke-trail wind profile obtained on September 25, 1962. Trail 304; time interval of 60 seconds; height interval of 25 meters.
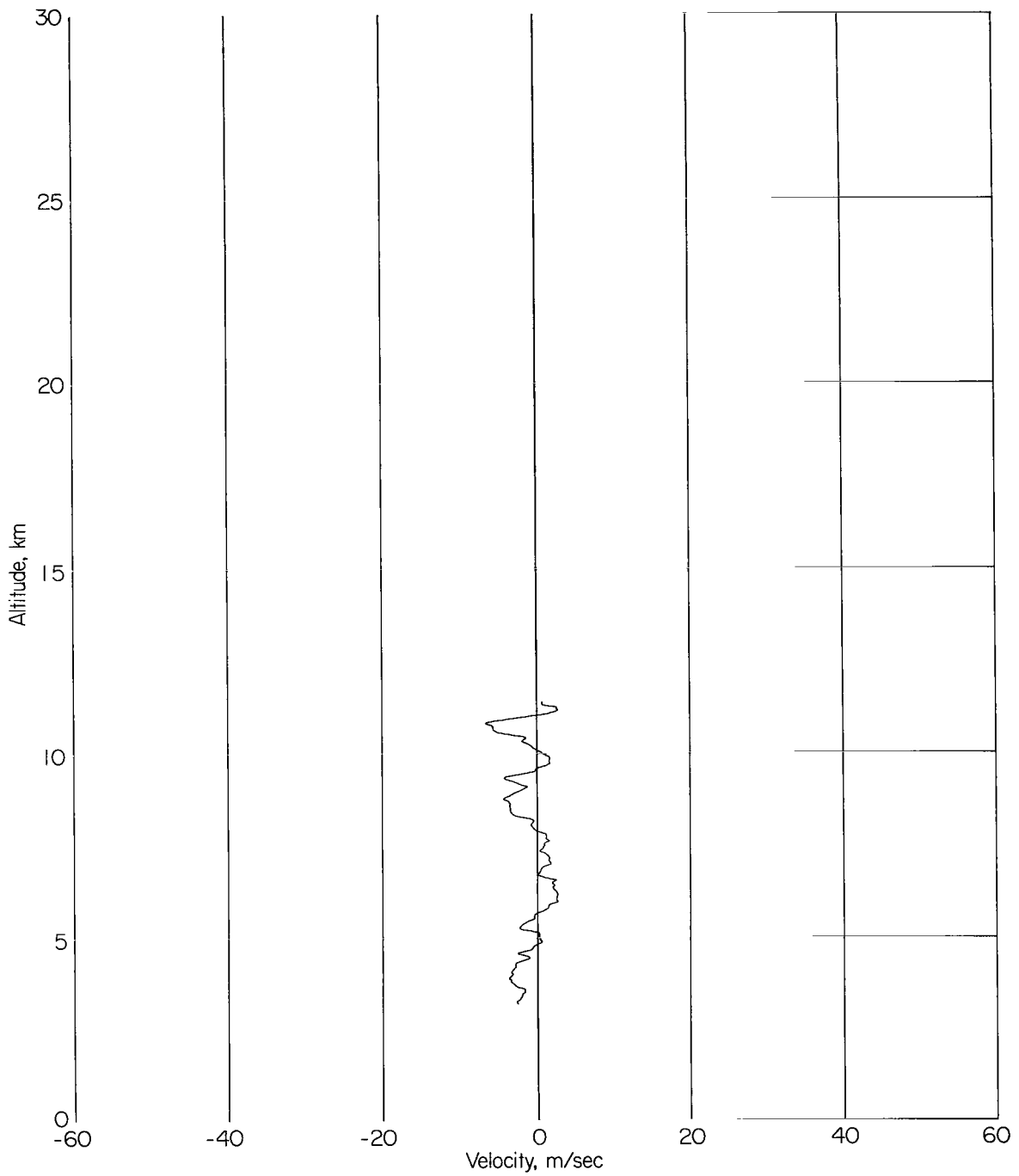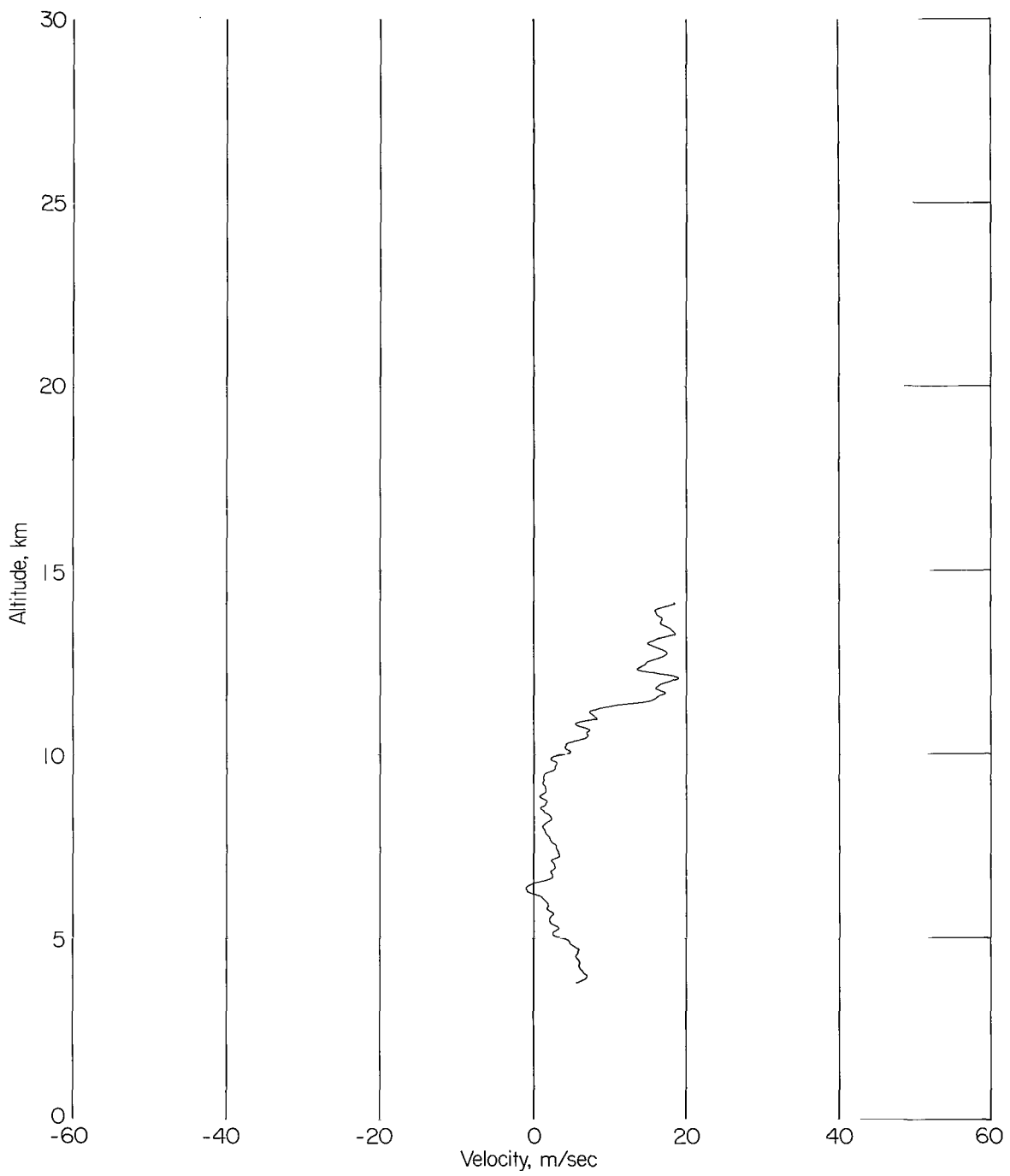
(b) South-to-north velocity component.

Figure 4.- Concluded.
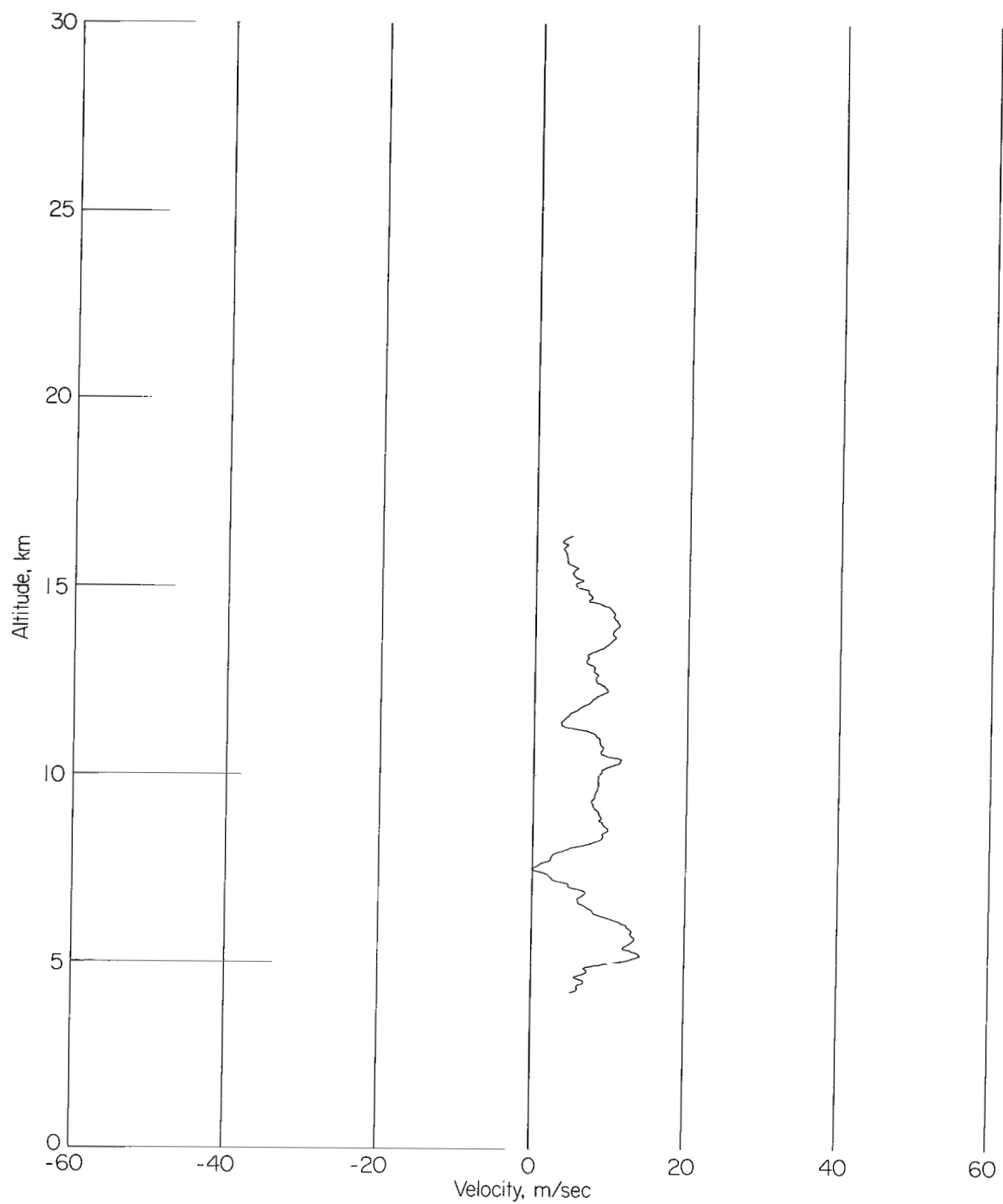
(a) West-to-east velocity component.

Figure 5.- Smoke-trail wind profile obtained on October 8, 1962. Trail 305; time interval of 60 seconds; height interval of 25 meters.
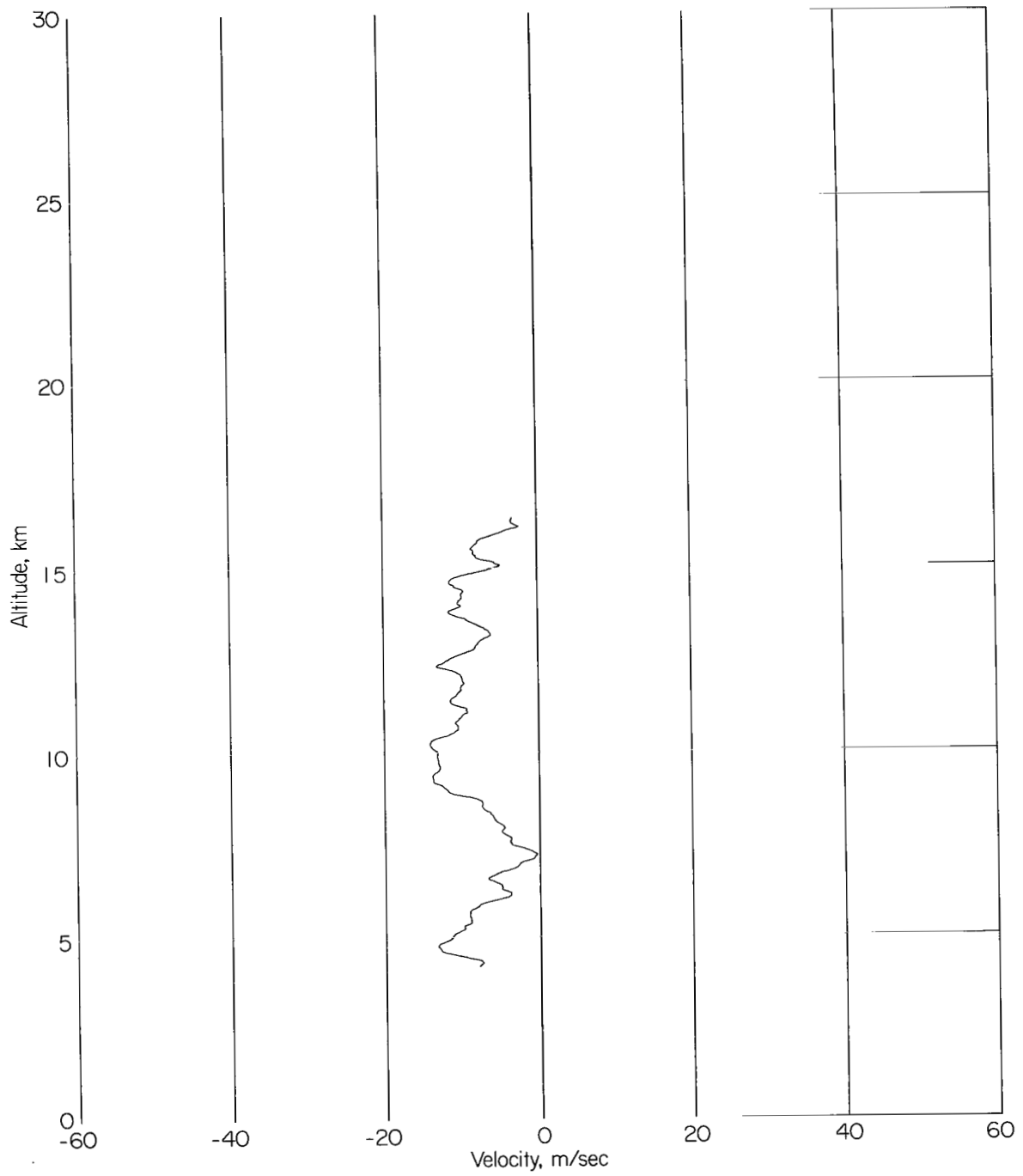
(b) South-to-north velocity component.

Figure 5.- Concluded.
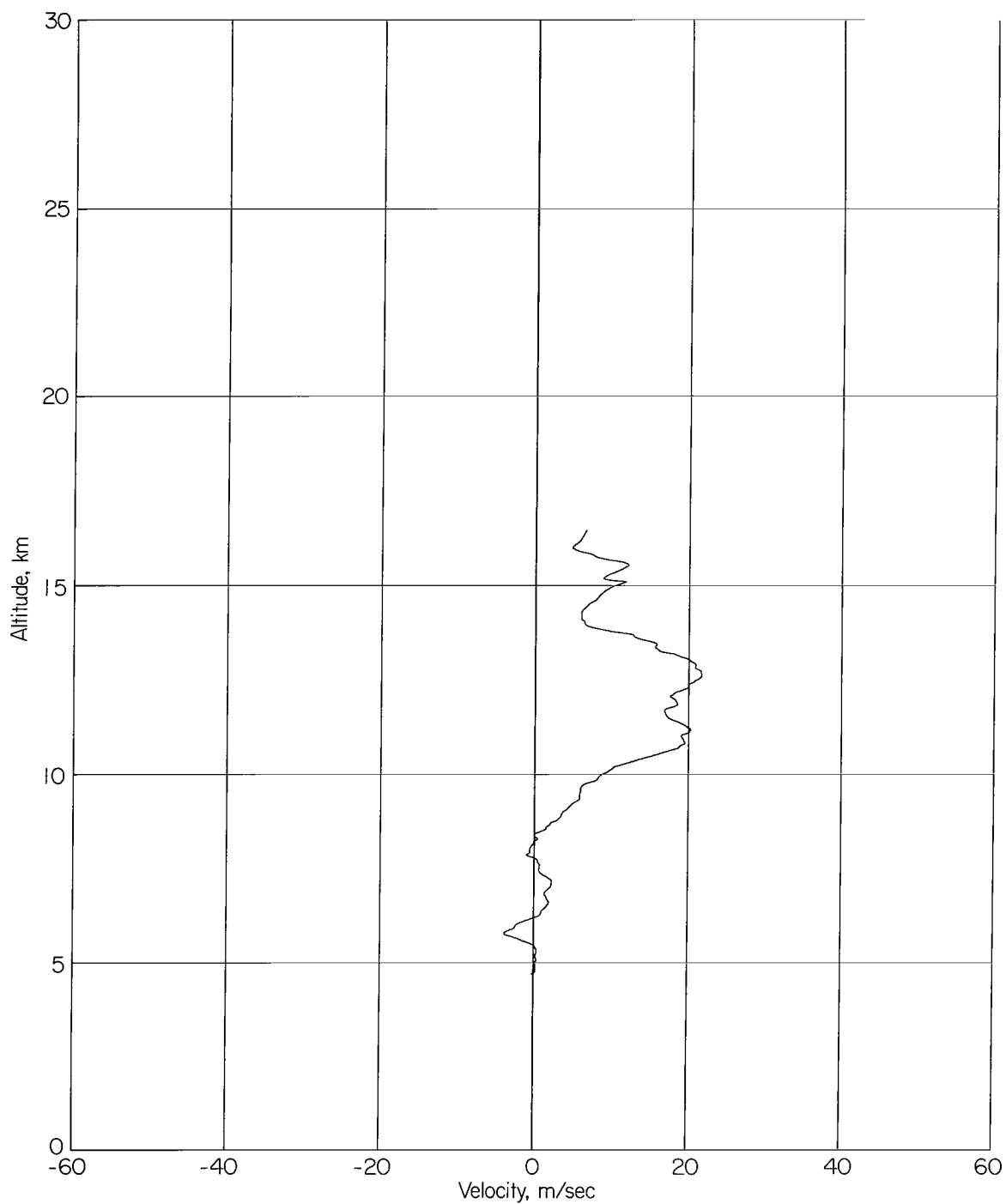
(a) West-to-east velocity component.

Figure 6.- Smoke-trail wind profile obtained on October 10, 1962. Trail 306; time interval of 60 seconds; height interval of 25 meters.
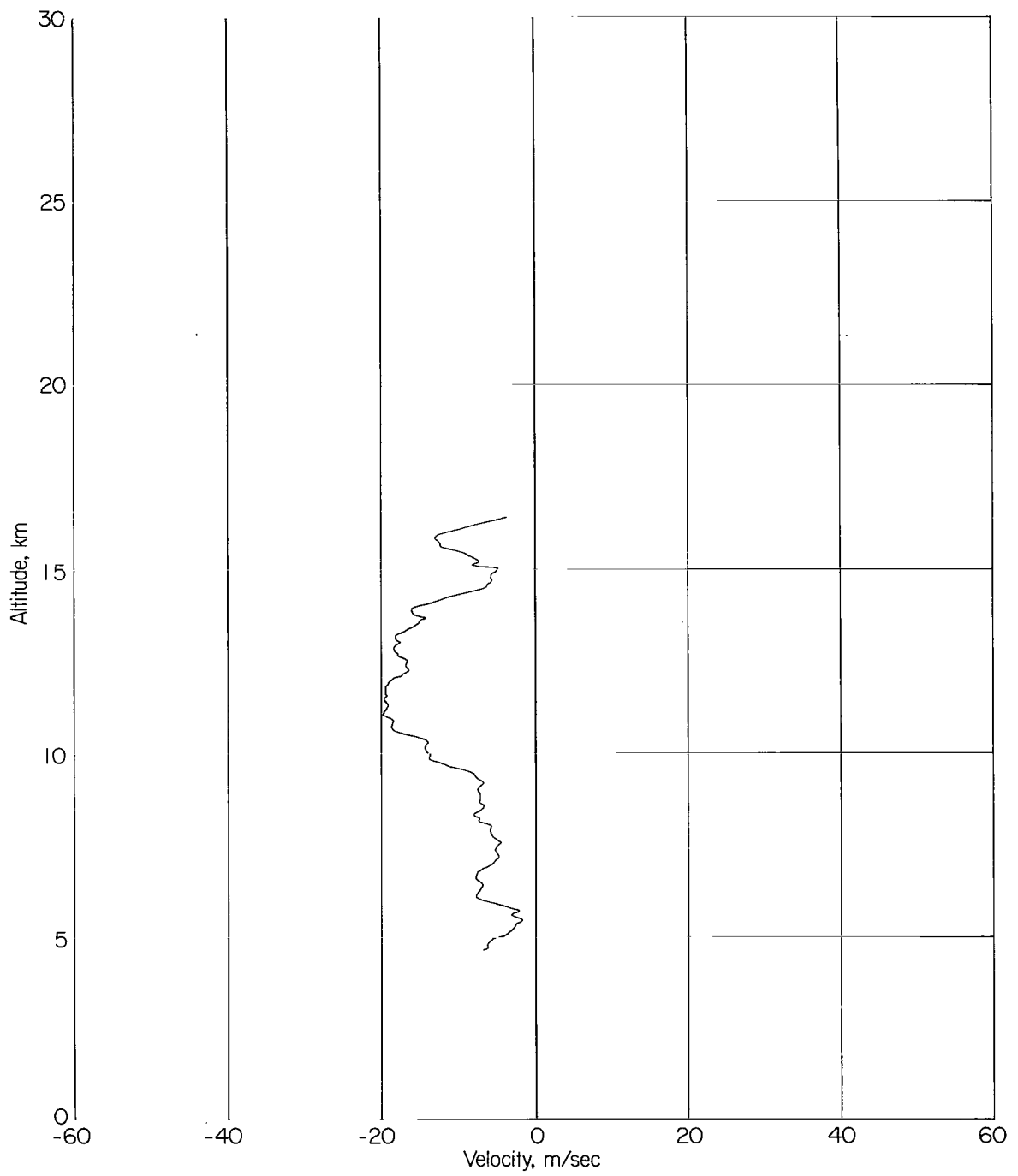
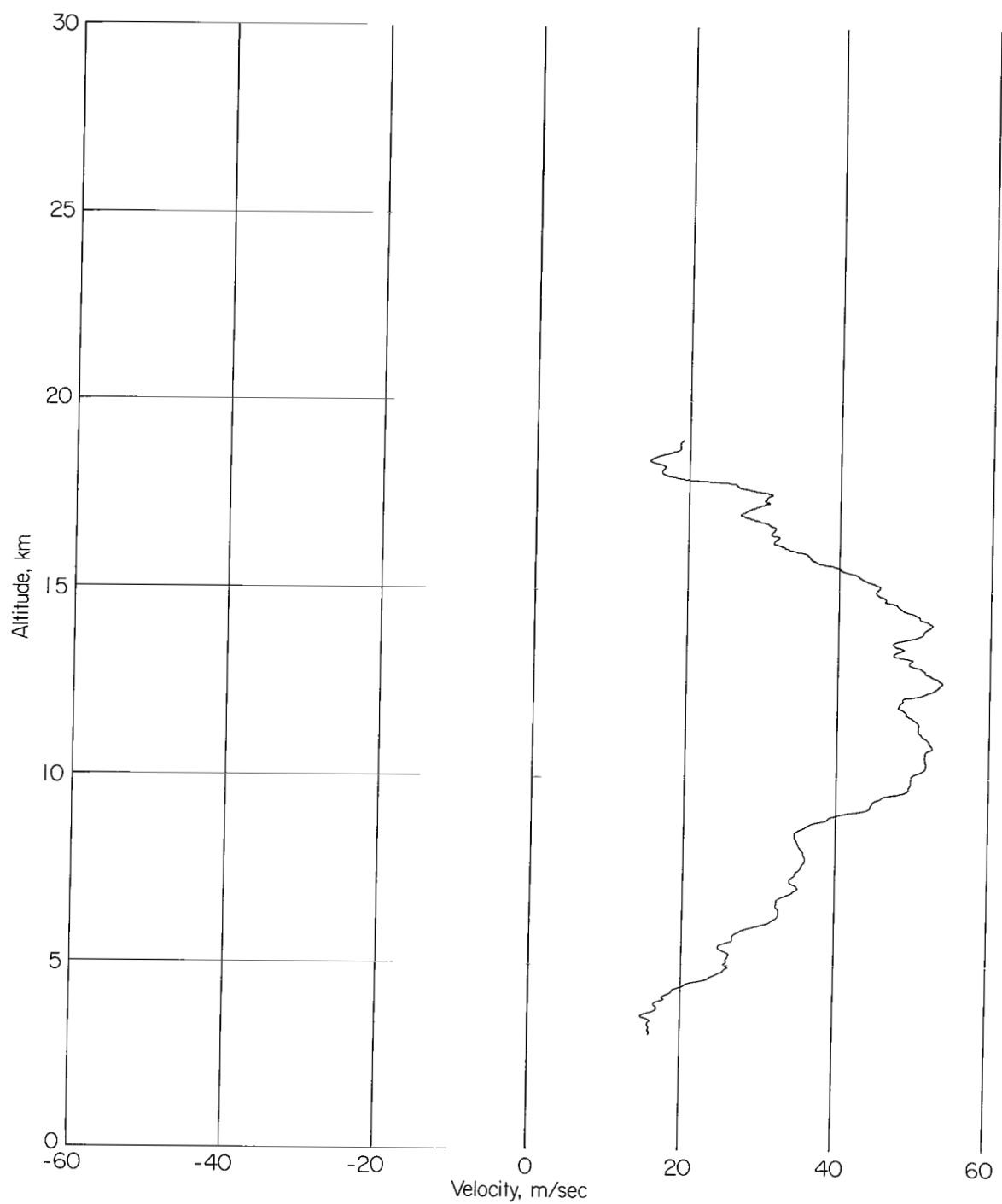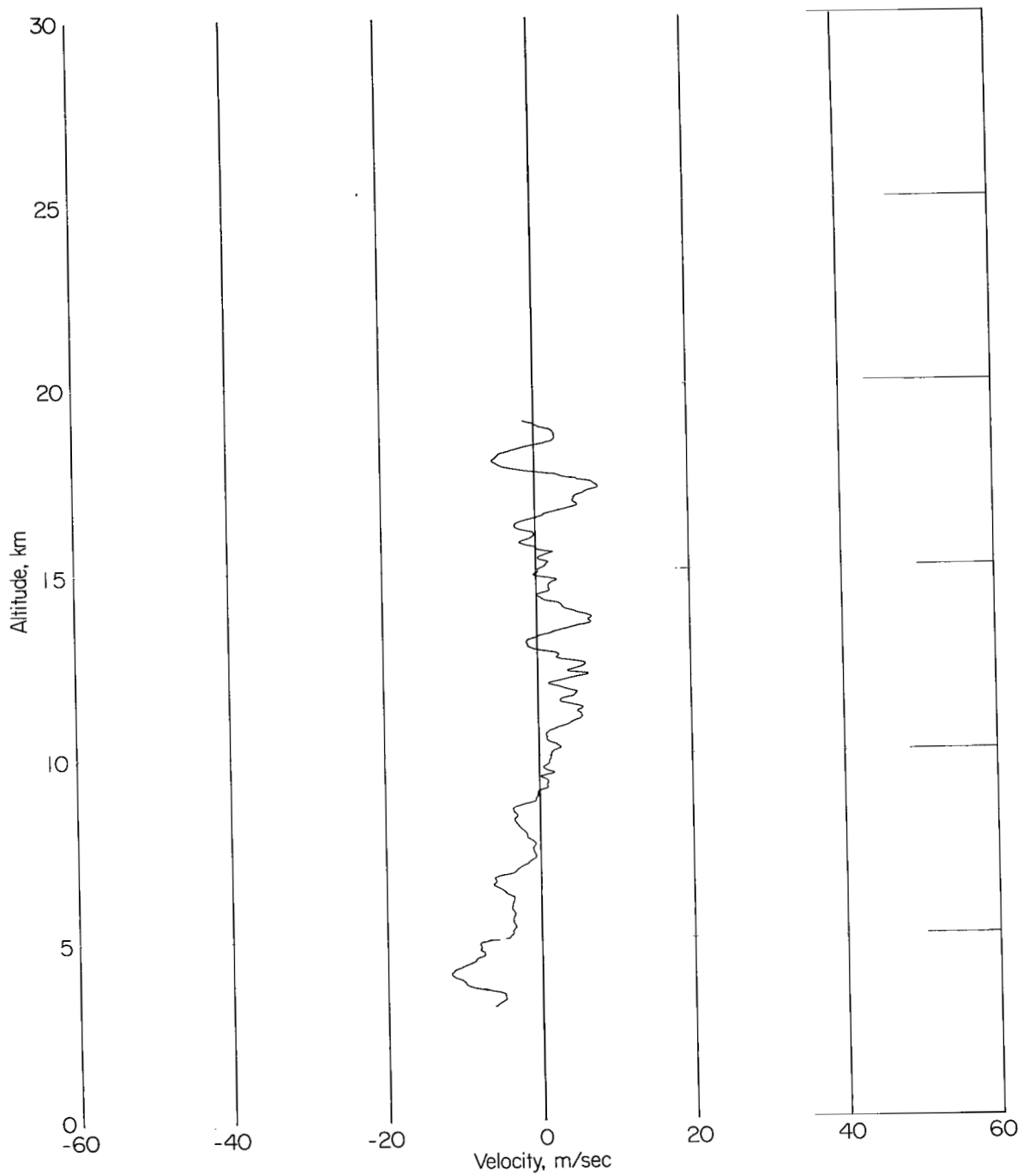(b) South-to-north velocity component.

Figure 6.- Concluded.
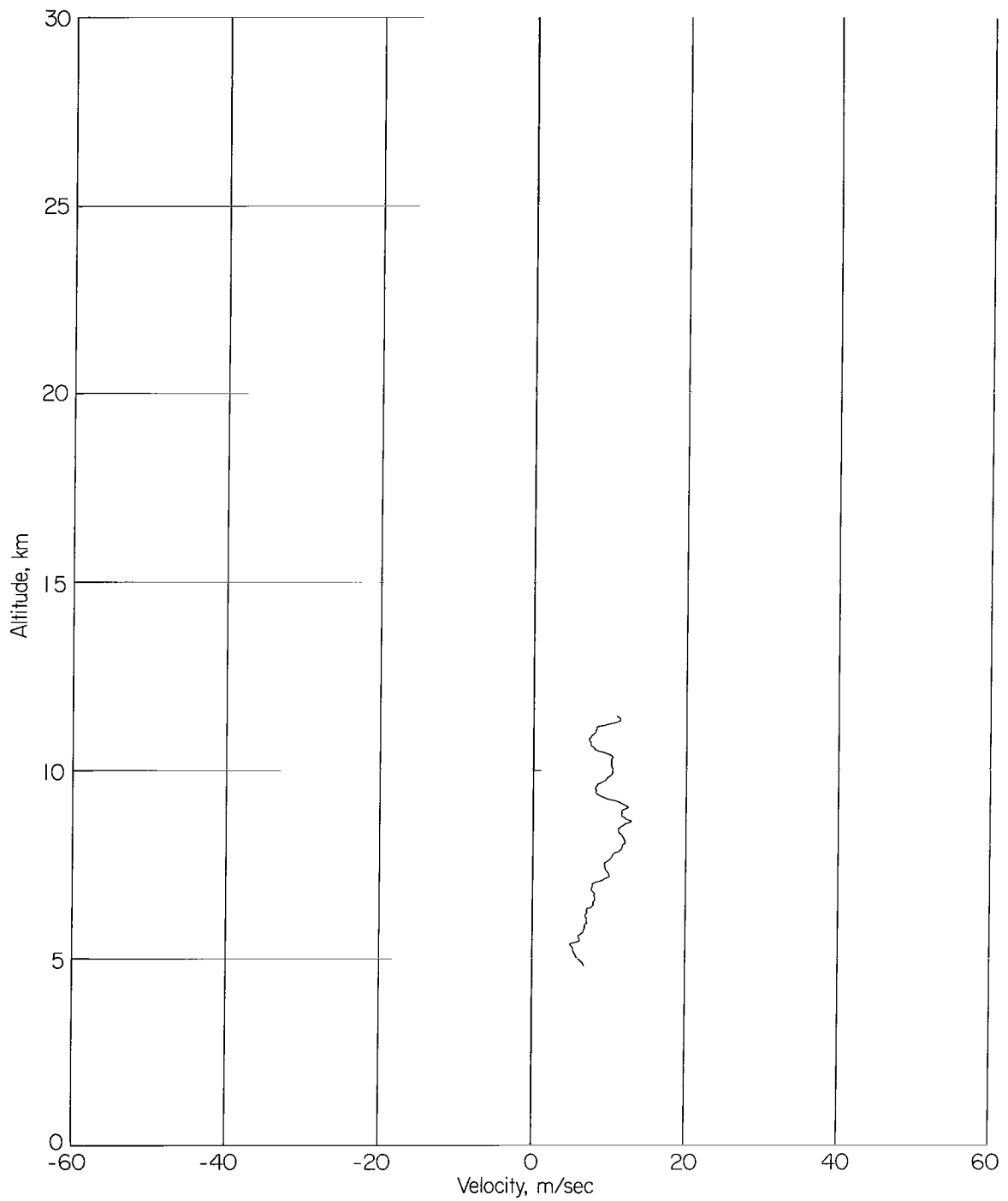
(a) West-to-east velocity component.

Figure 7.- Smoke-trail wind profile obtained on October 19, 1962. Trail 307; time interval of 60 seconds; height interval of 25 meters.
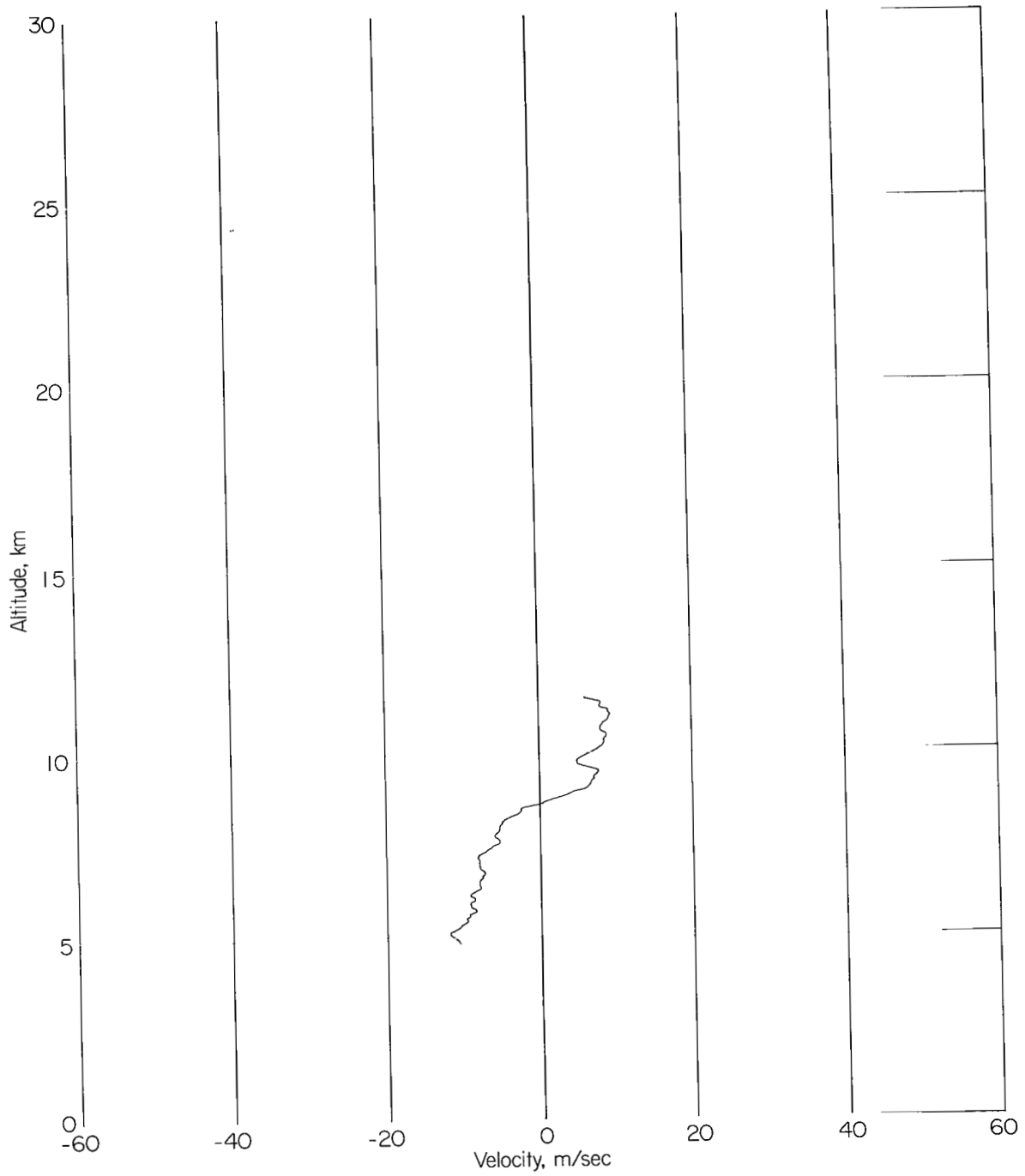
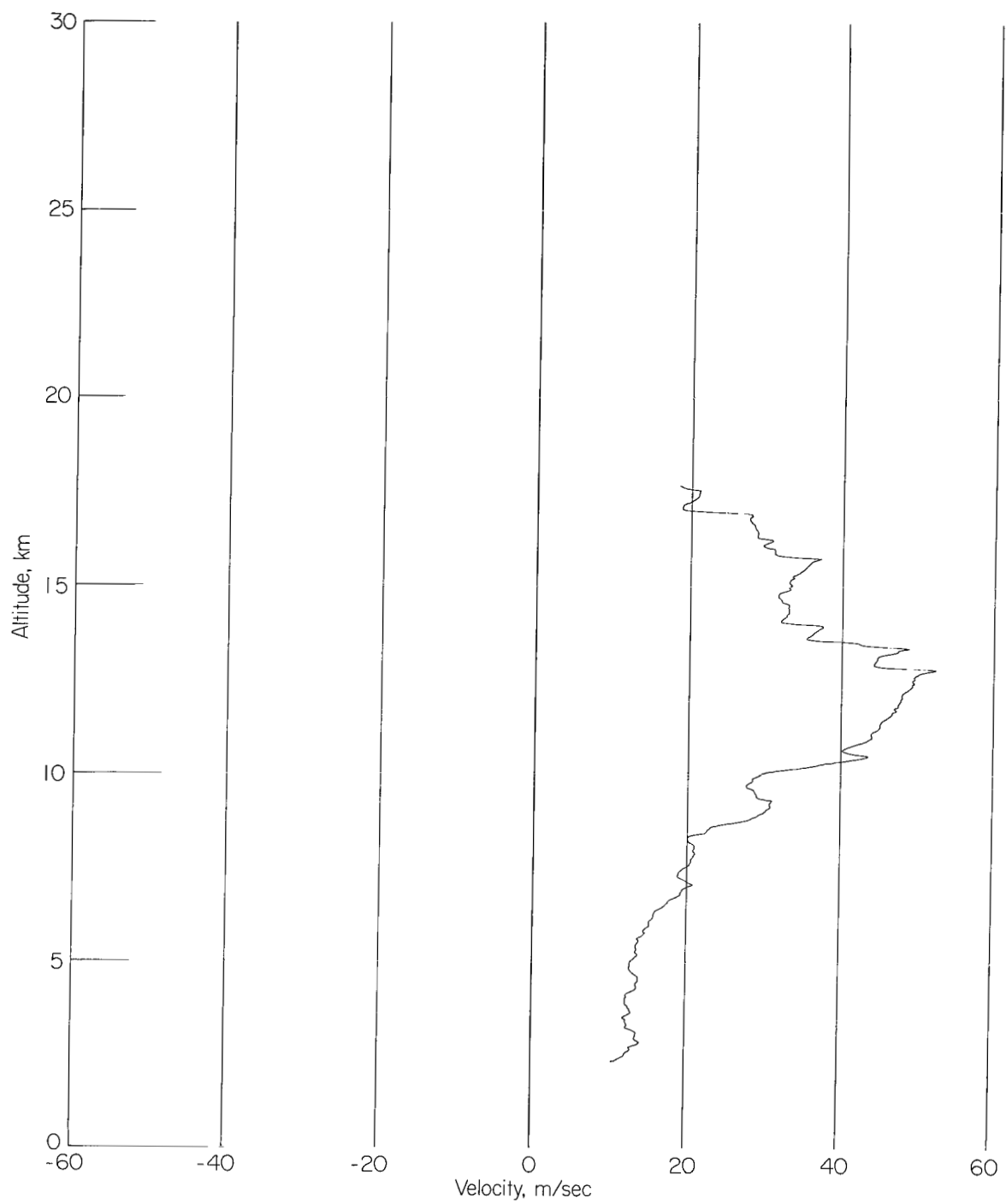(b) South-to-north velocity component.

Figure 7.- Concluded.
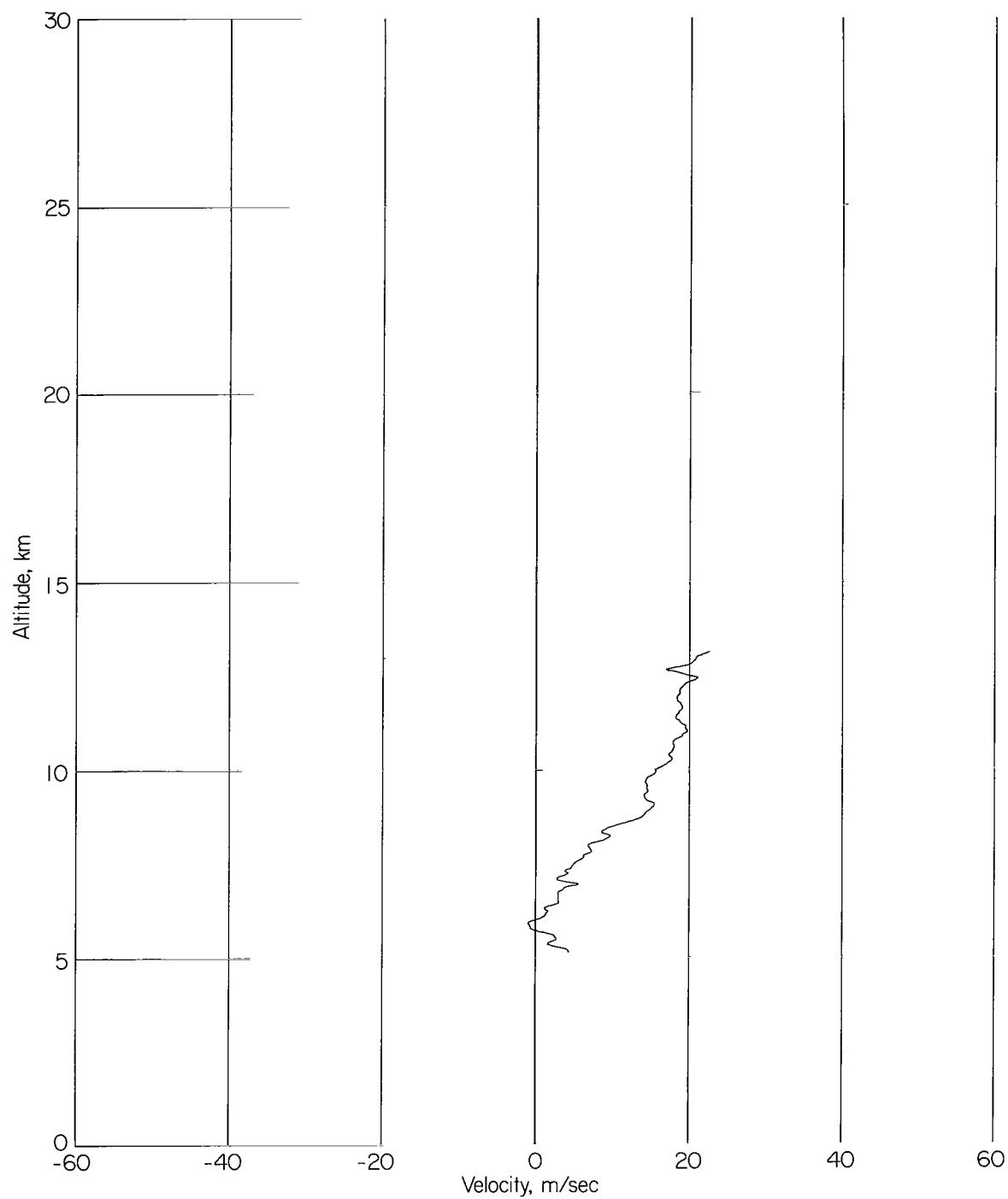
(a) West-to-east velocity component.

Figure 8.- Smoke-trail wind profile obtained on October 29, 1962. Trail 308; time interval of 60 seconds; height interval of 25 meters.
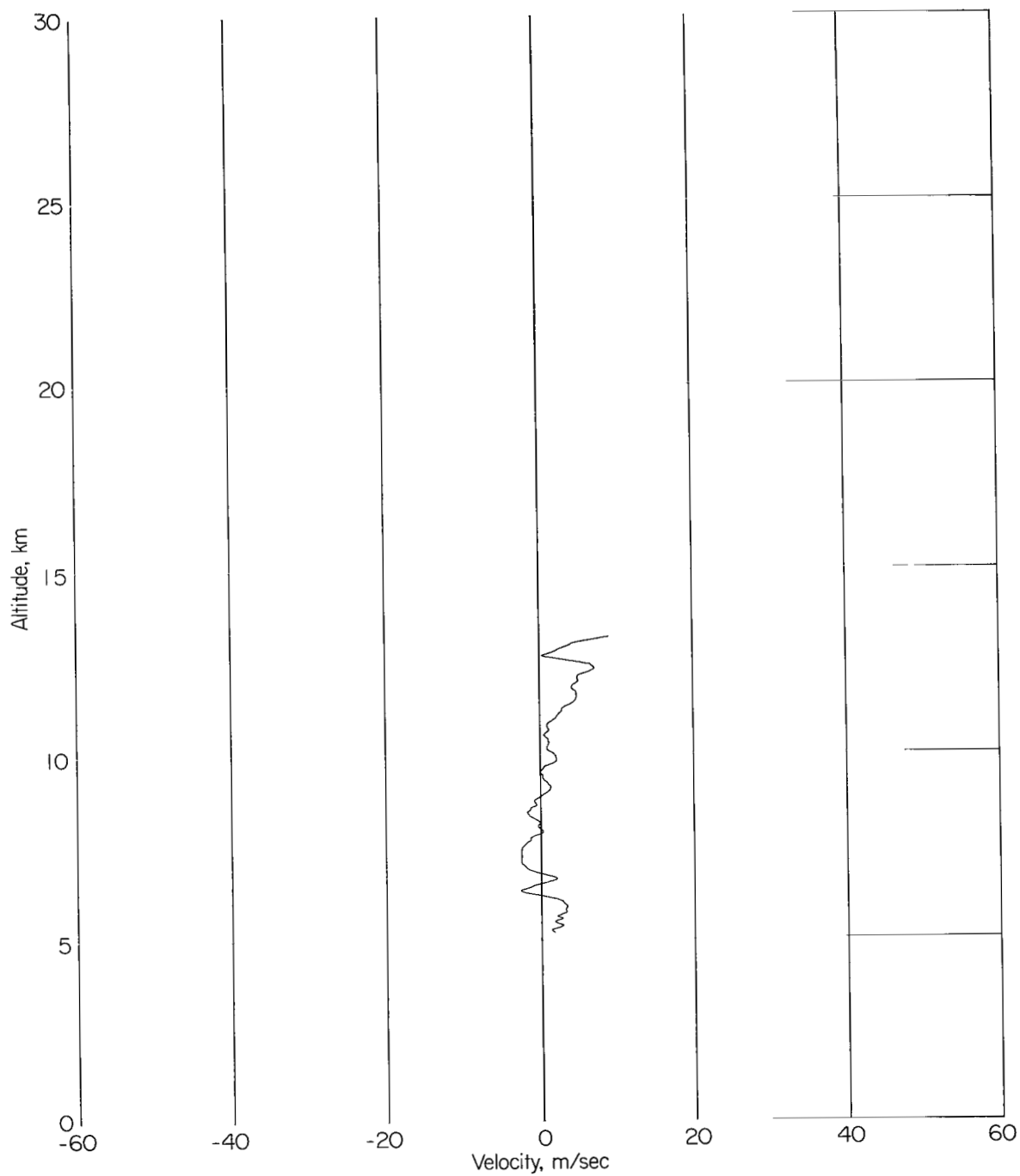
(b) South-to-north velocity component.

Figure 8.- Concluded.
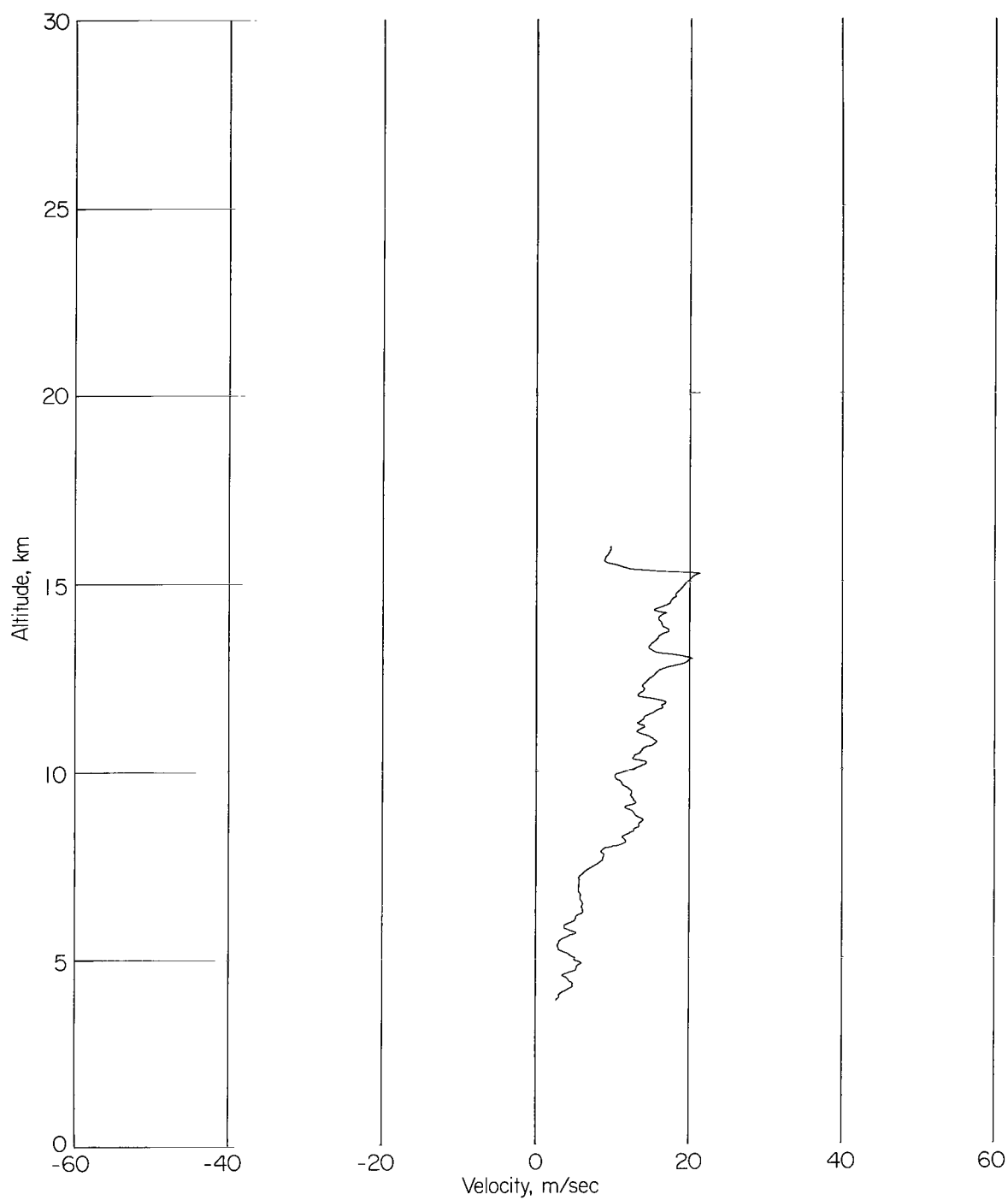
(a) West-to-east velocity component.

Figure 9.- Smoke-trail wind profile obtained on November 1, 1962. Trail 309; time interval of 60 seconds; height interval of 25 meters.
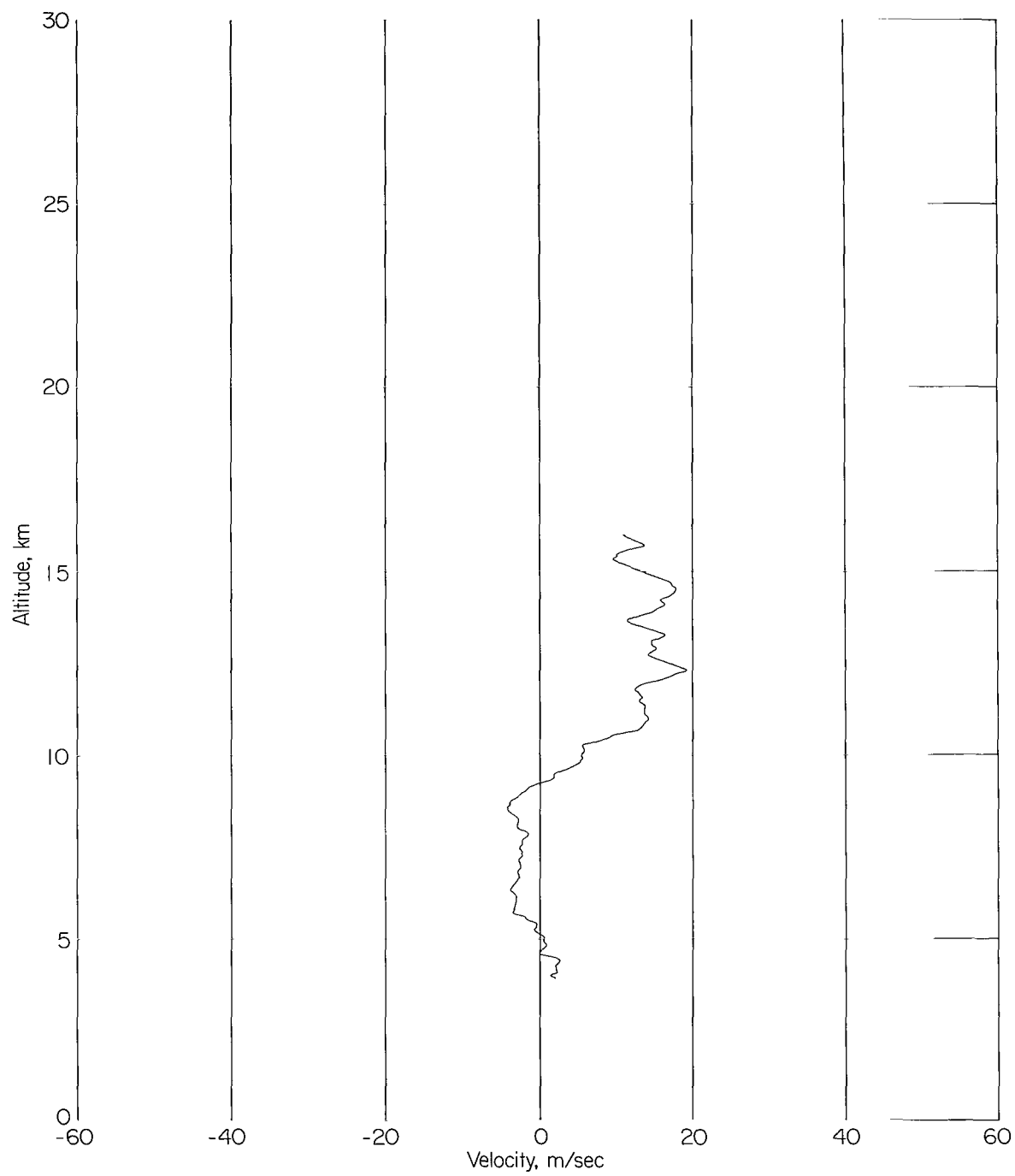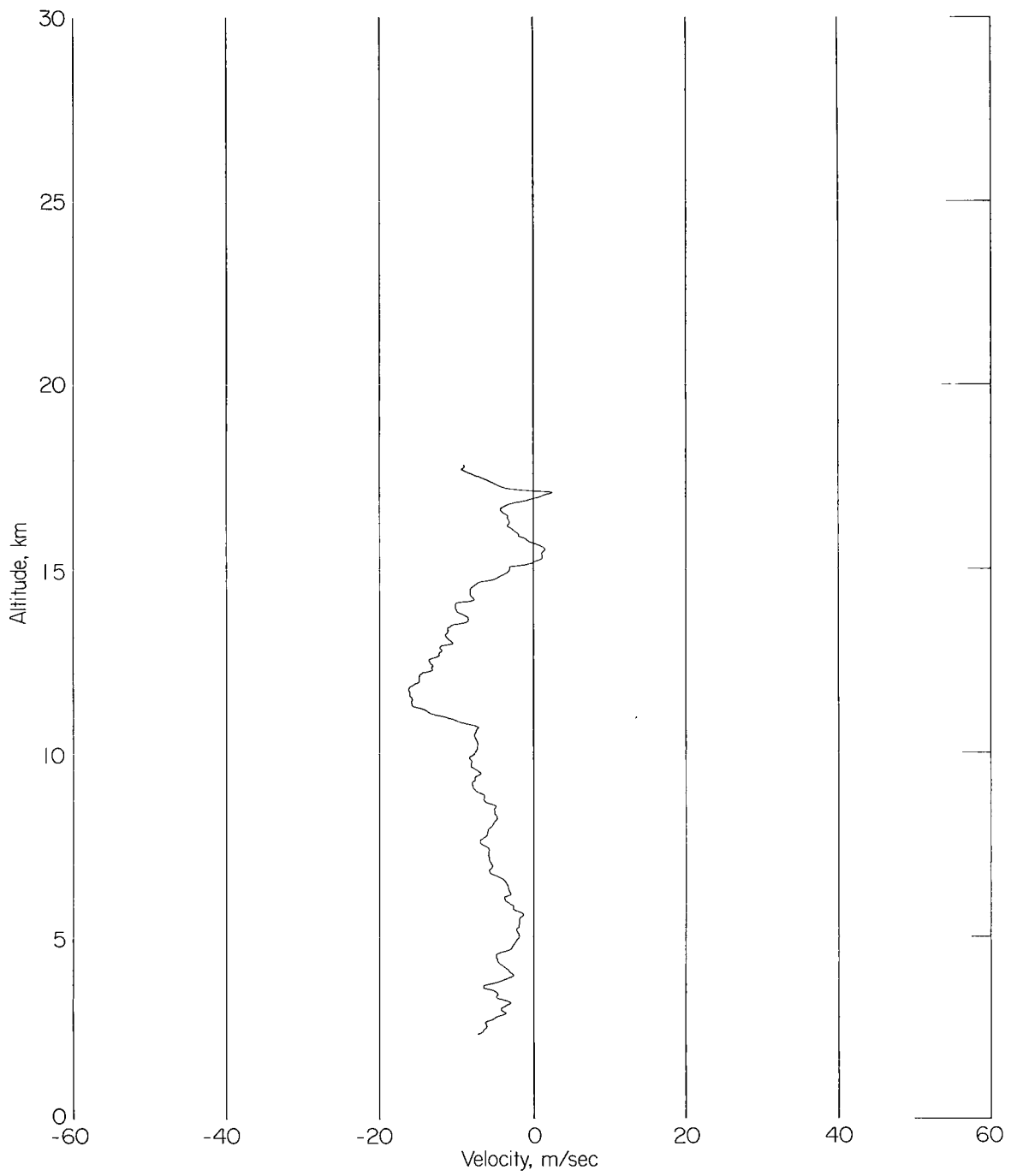
(b) South-to-north velocity component.

Figure 9.- Concluded.
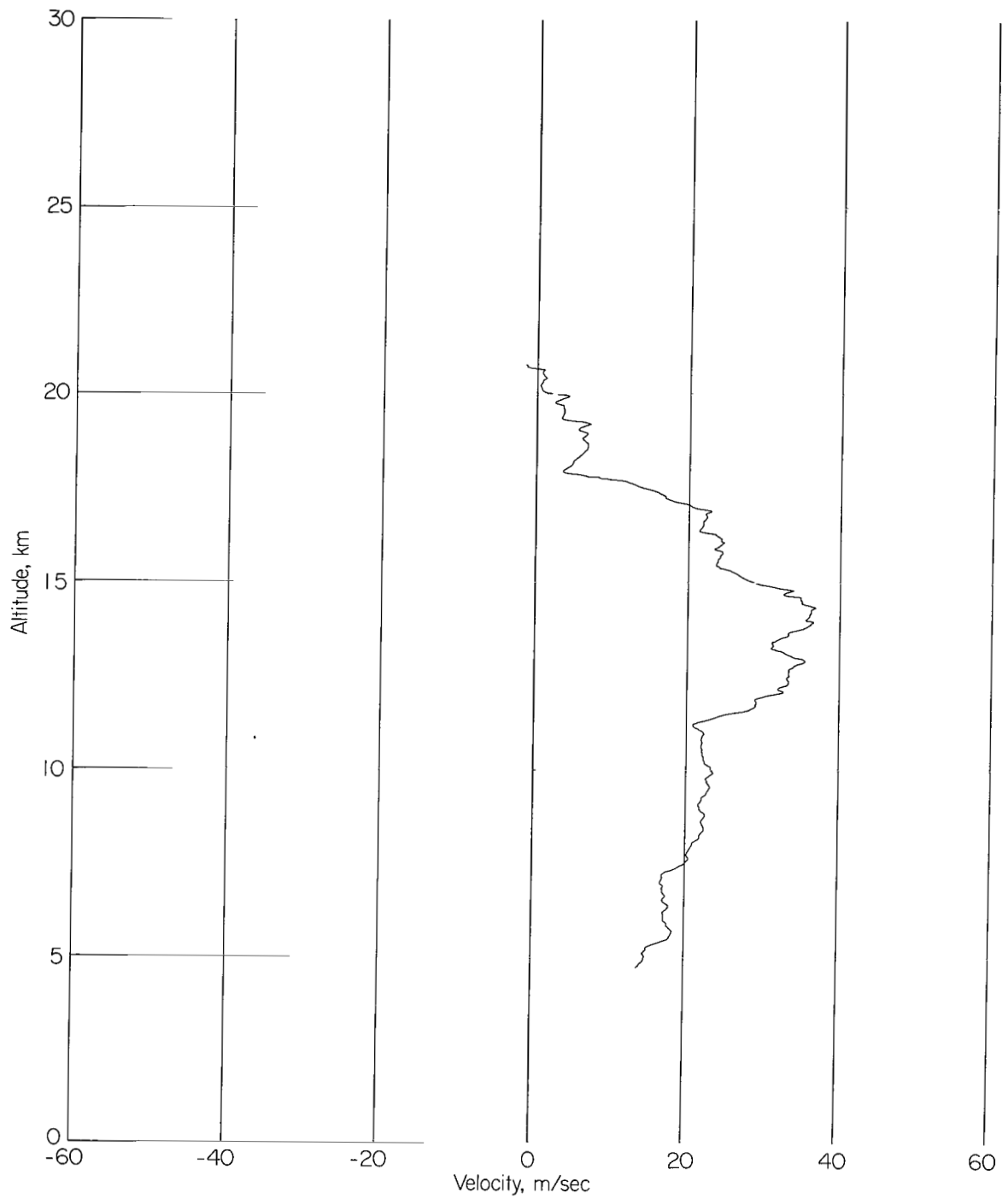
(a) West-to-east velocity component.

Figure 10.- Smoke-trail wind profile obtained on November 5, 1962.   Trail 310; time interval of 60 seconds; height interval of 25 meters.
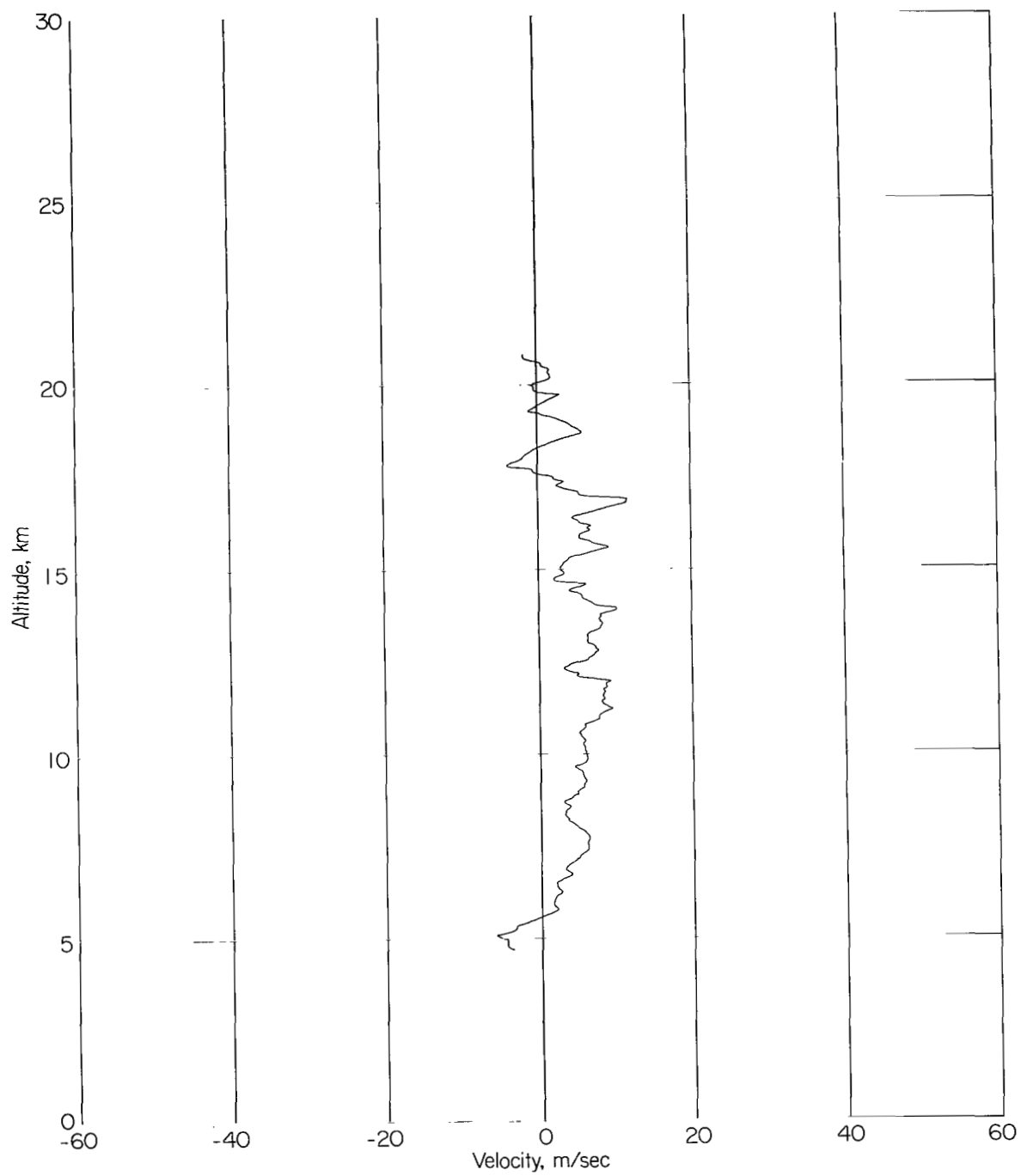
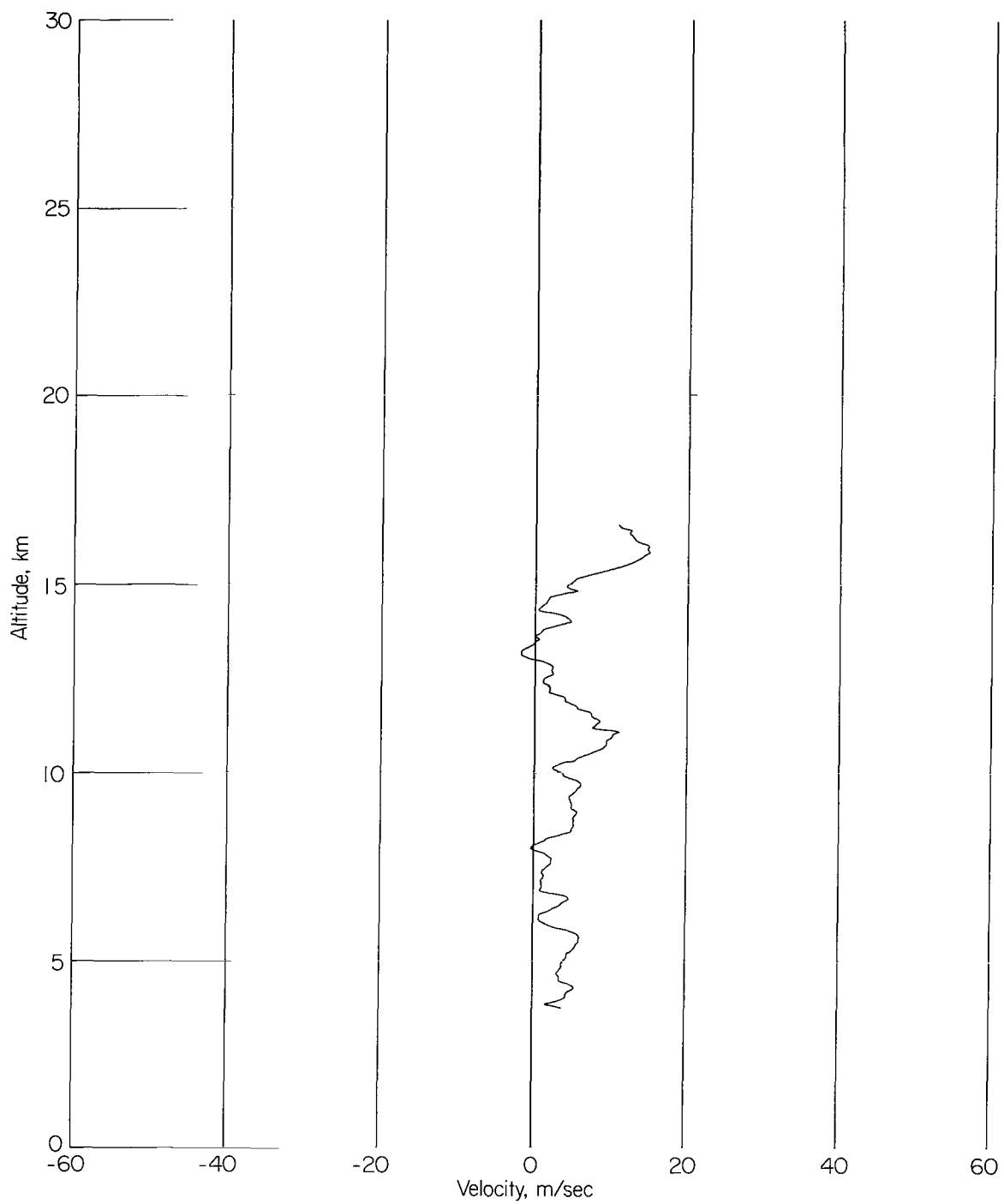(b) South-to-north velocity component.

Figure 10.- Concluded.
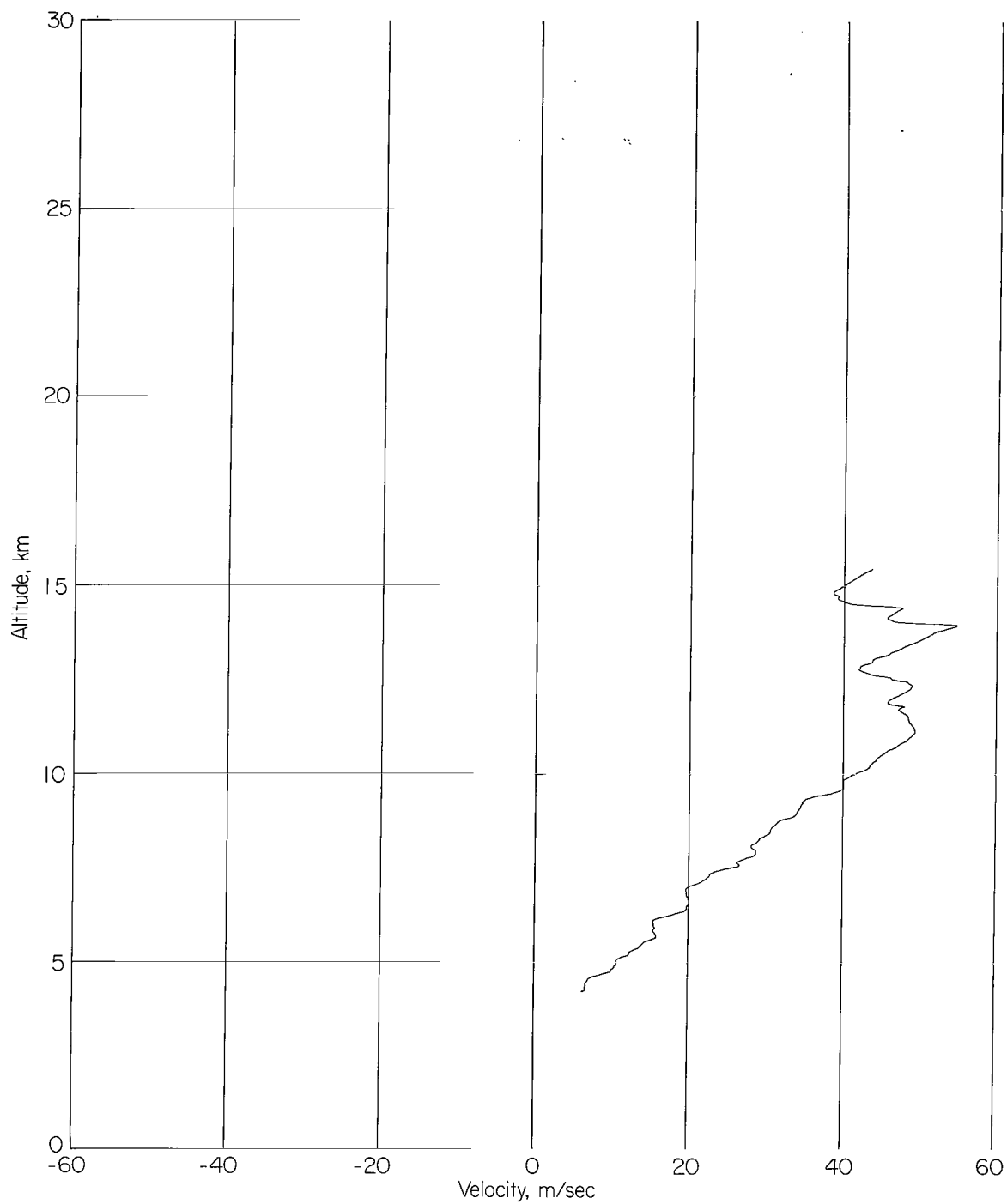
(a) West-to-east velocity component.

Figure 11.- Smoke-trail wind profile obtained on November 6, 1962. Trail 311; time interval of 60 seconds; height interval of 25 meters.
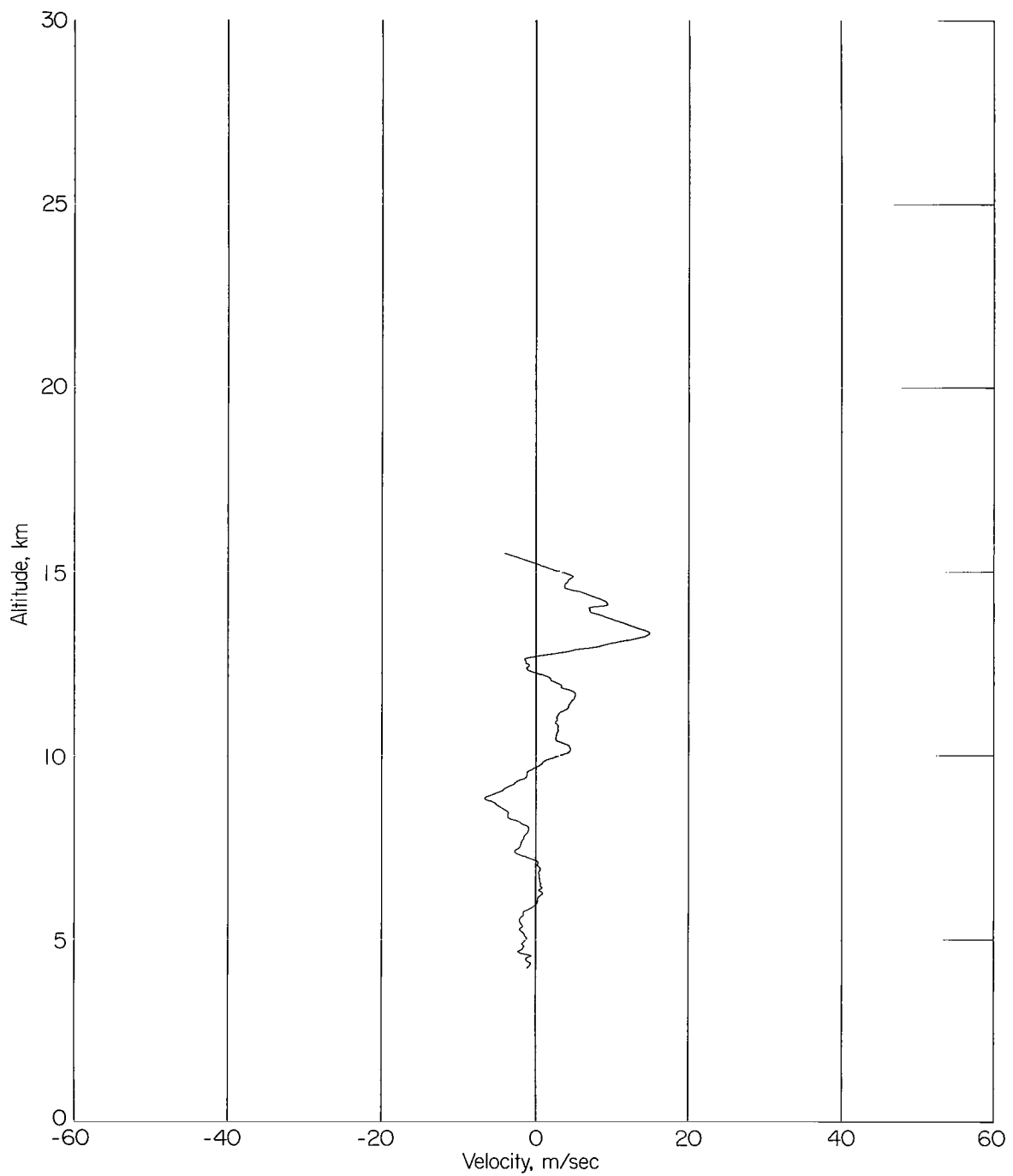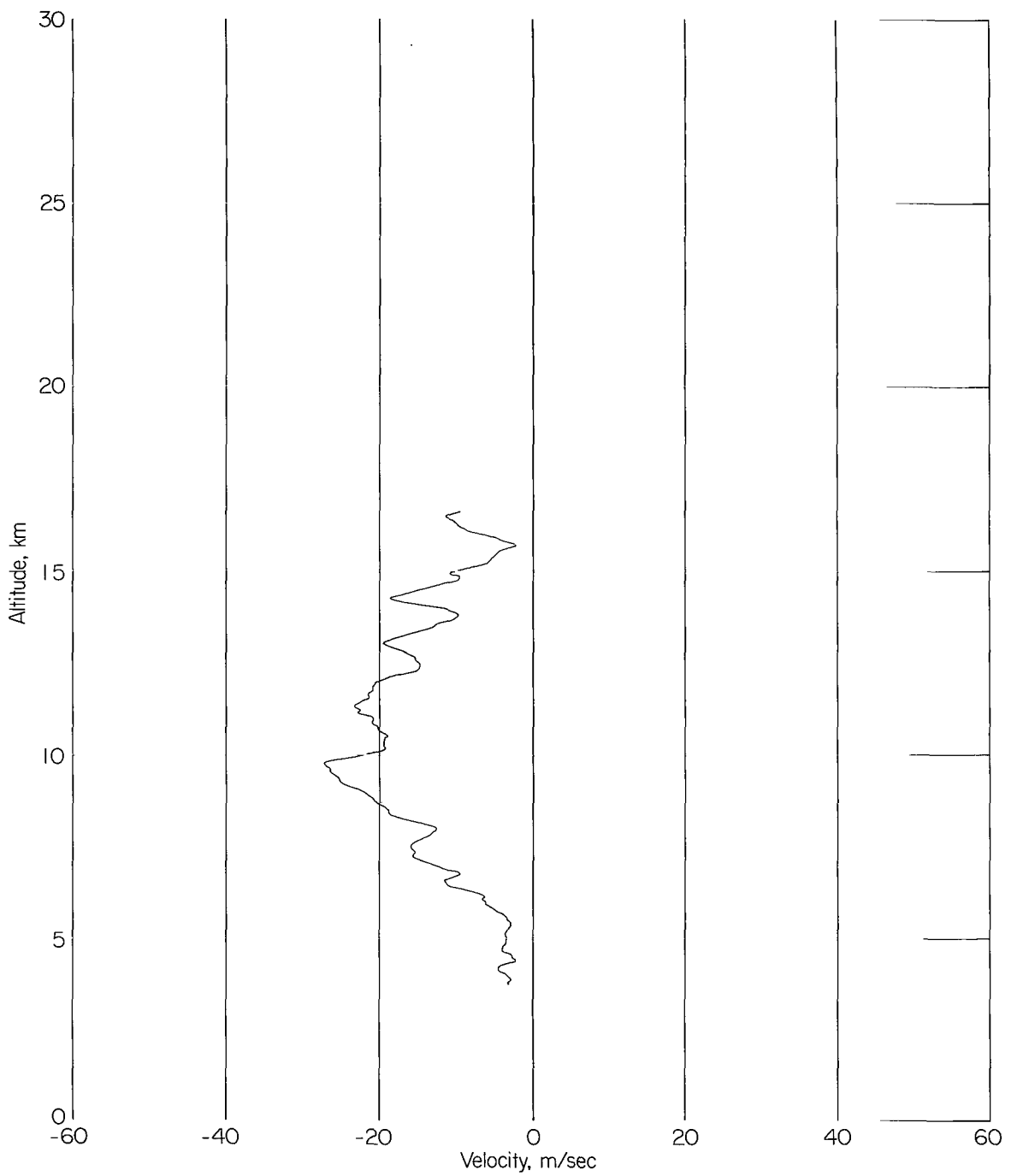
(b) South-to-north velocity component.

Figure 11.- Concluded.
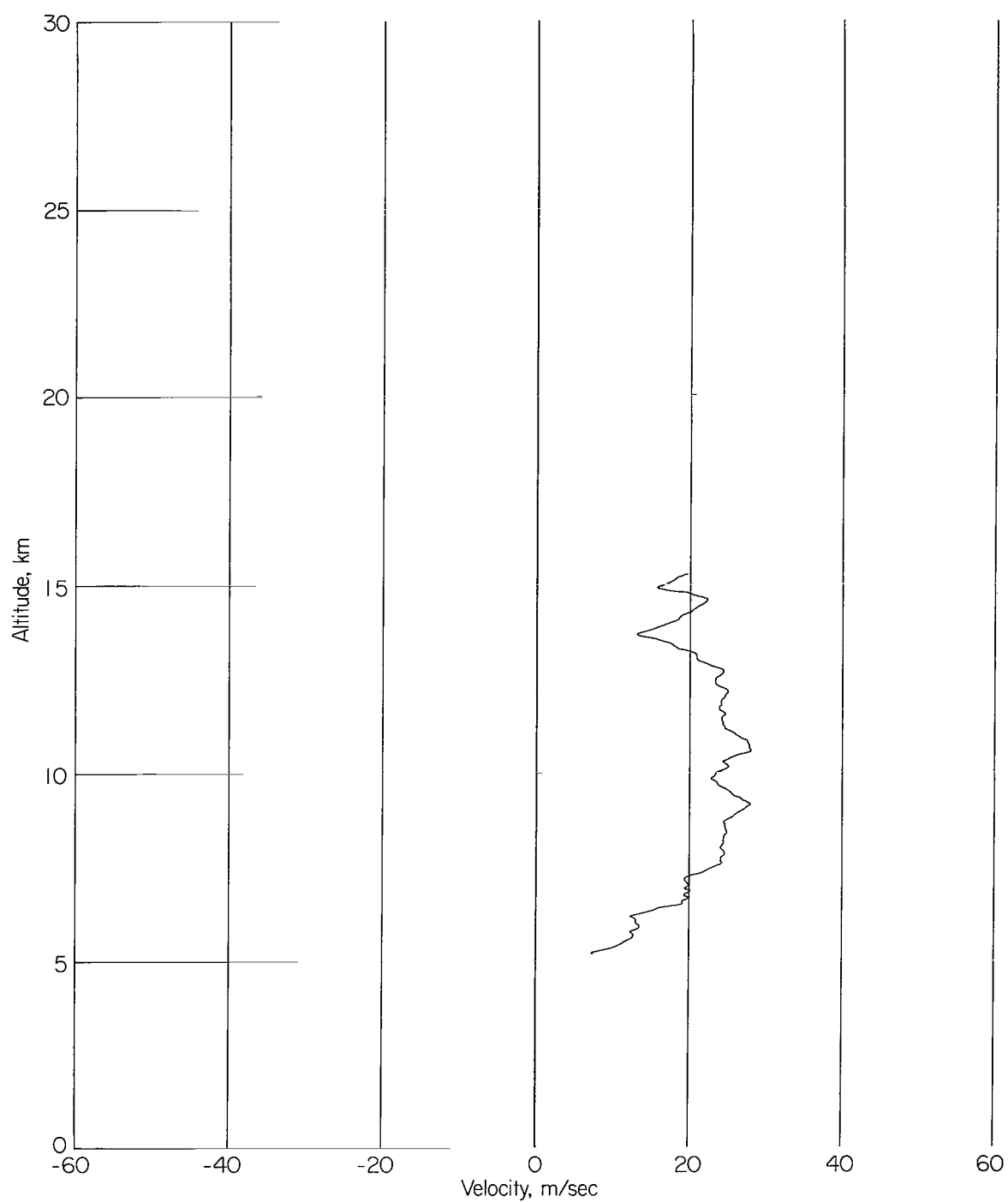
(a) West-to-east velocity component.

Figure 12.- Smoke-trail wind profile obtained on November 13, 1962. Trail 312; time interval of 60 seconds; height interval of 25 meters.
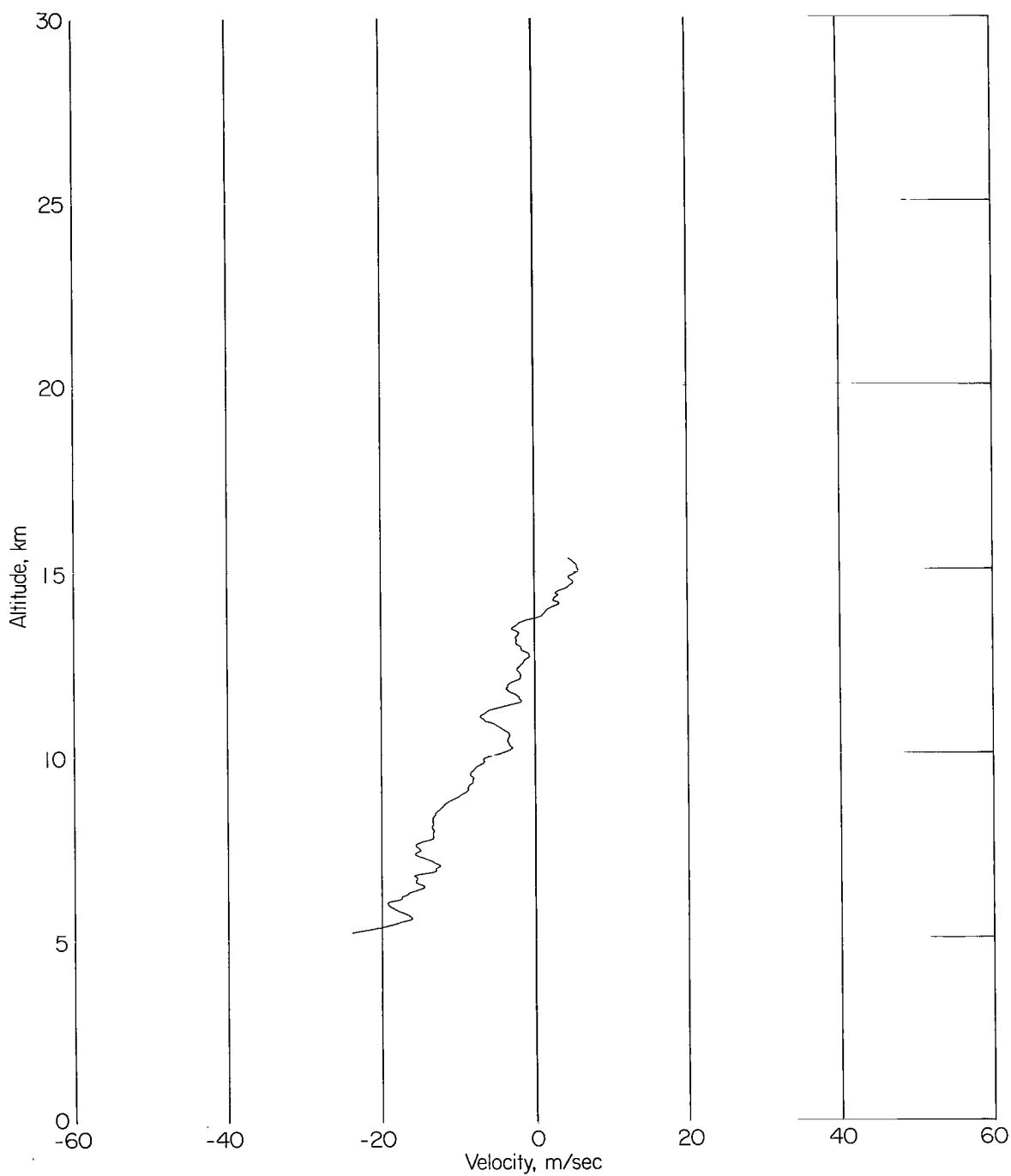
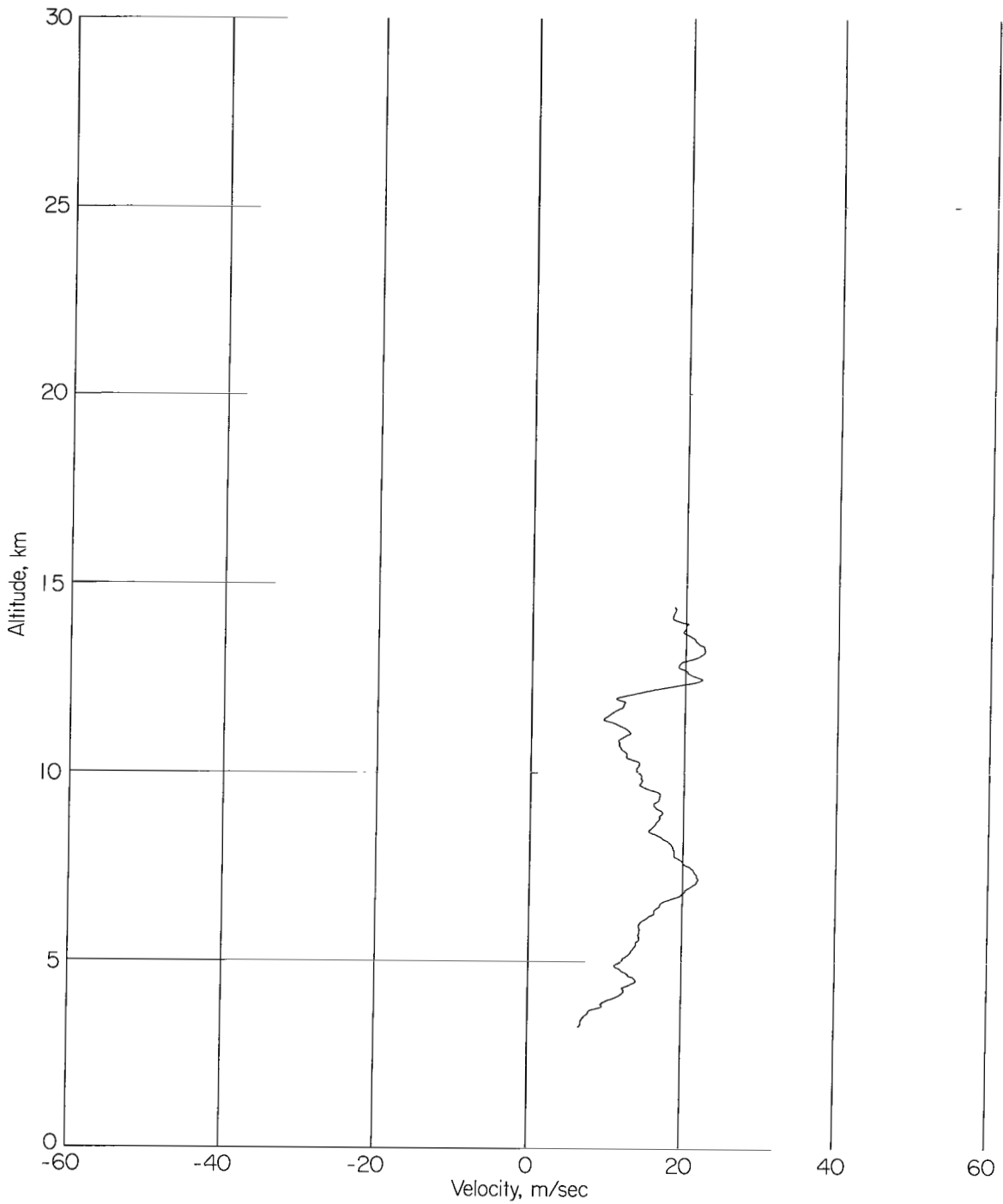(b) South-to-north velocity component.

Figure 12.- Concluded.
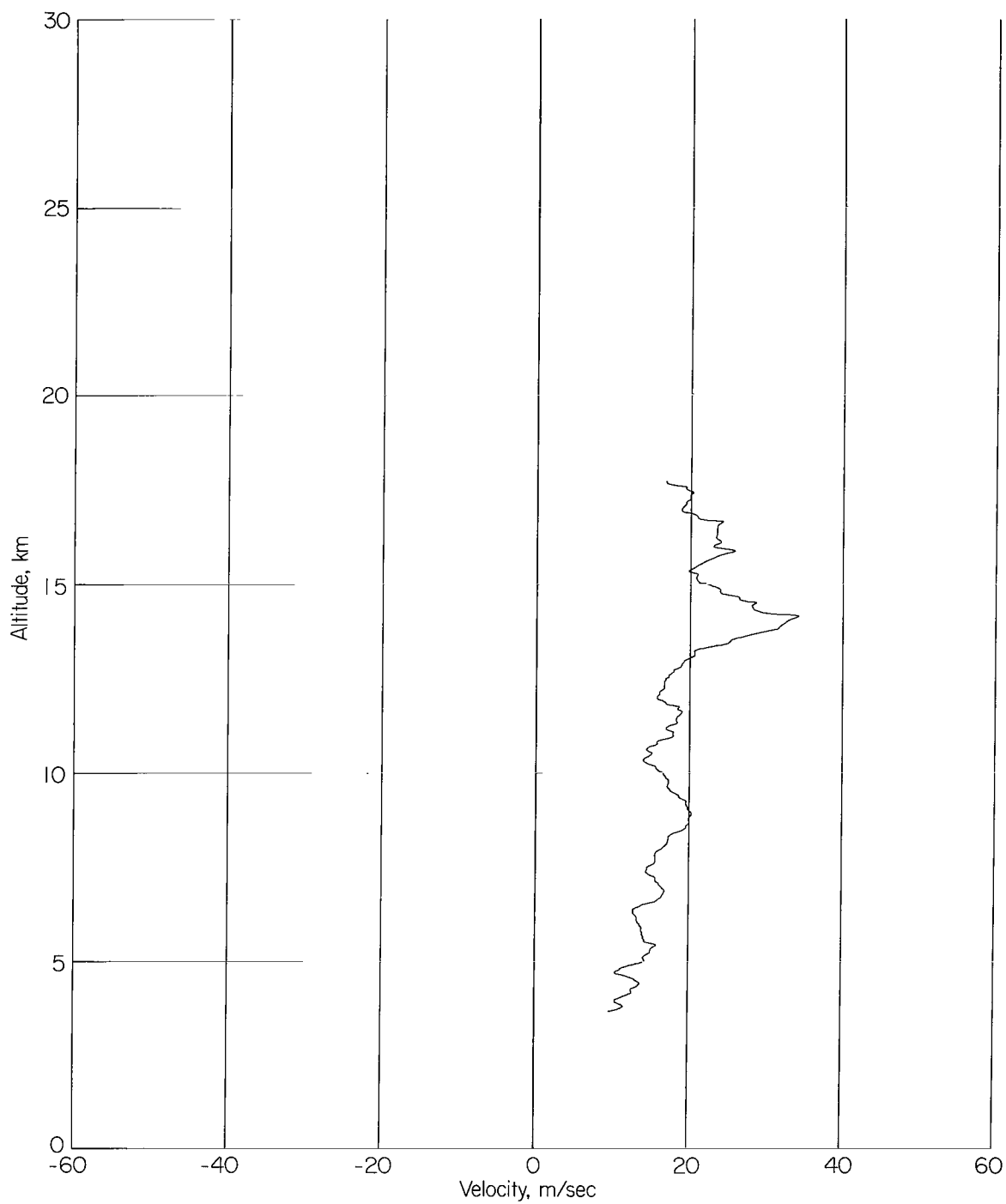
(a) West-to-east velocity component.

Figure 13.- Smoke-trail wind profile obtained on November 16, 1962. Trail 313; time interval of 60 seconds; height interval of 25 meters.
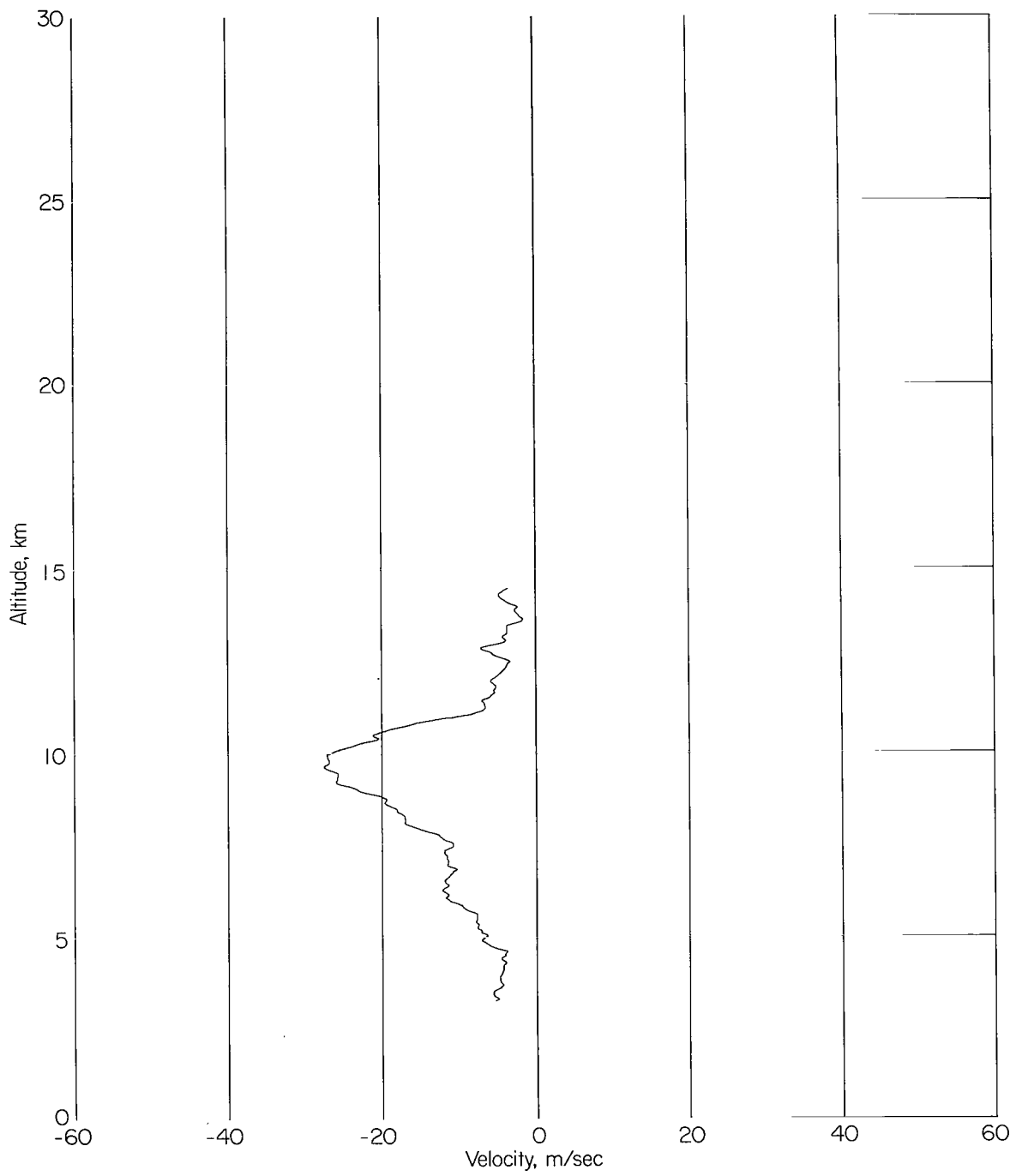
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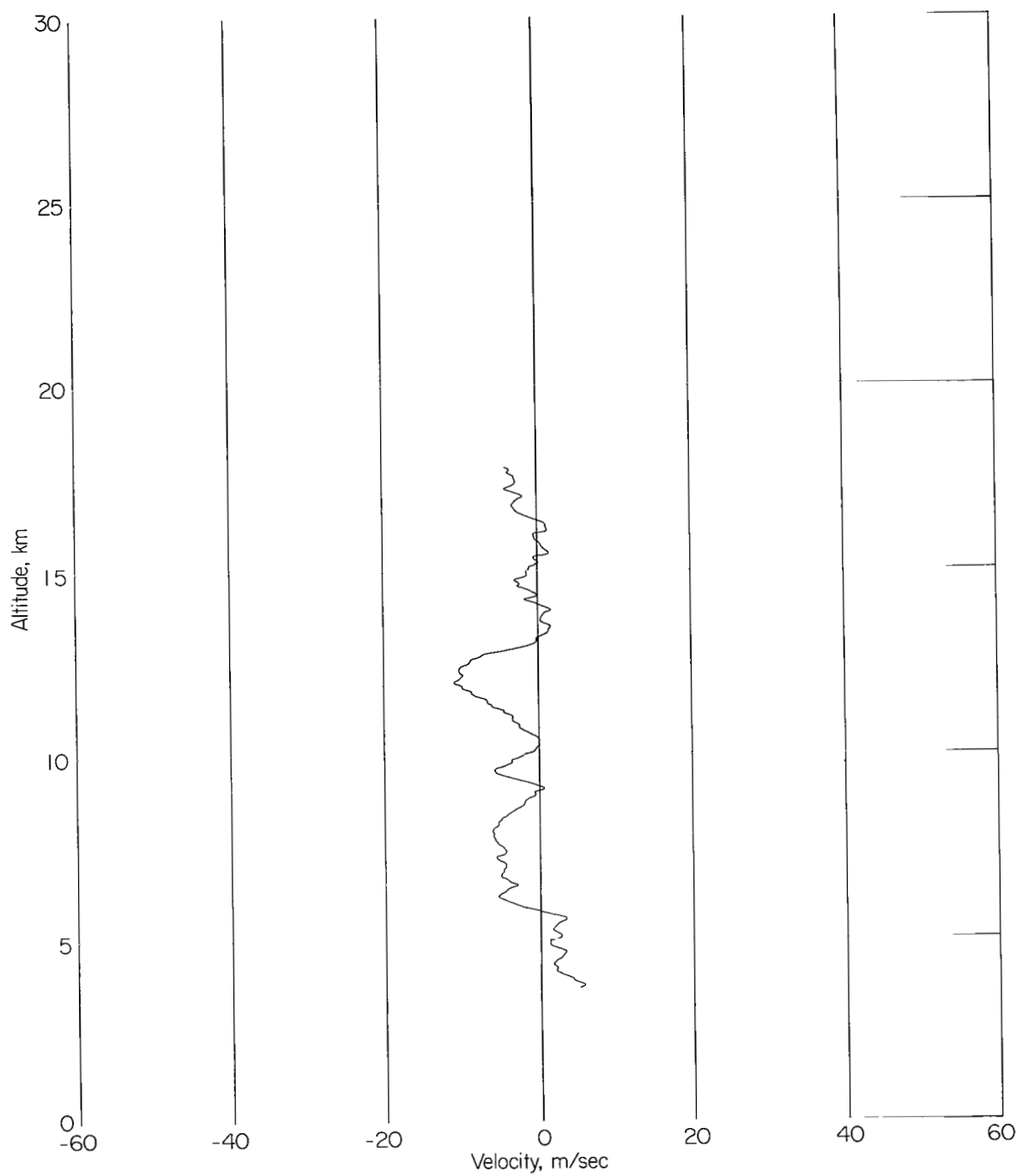
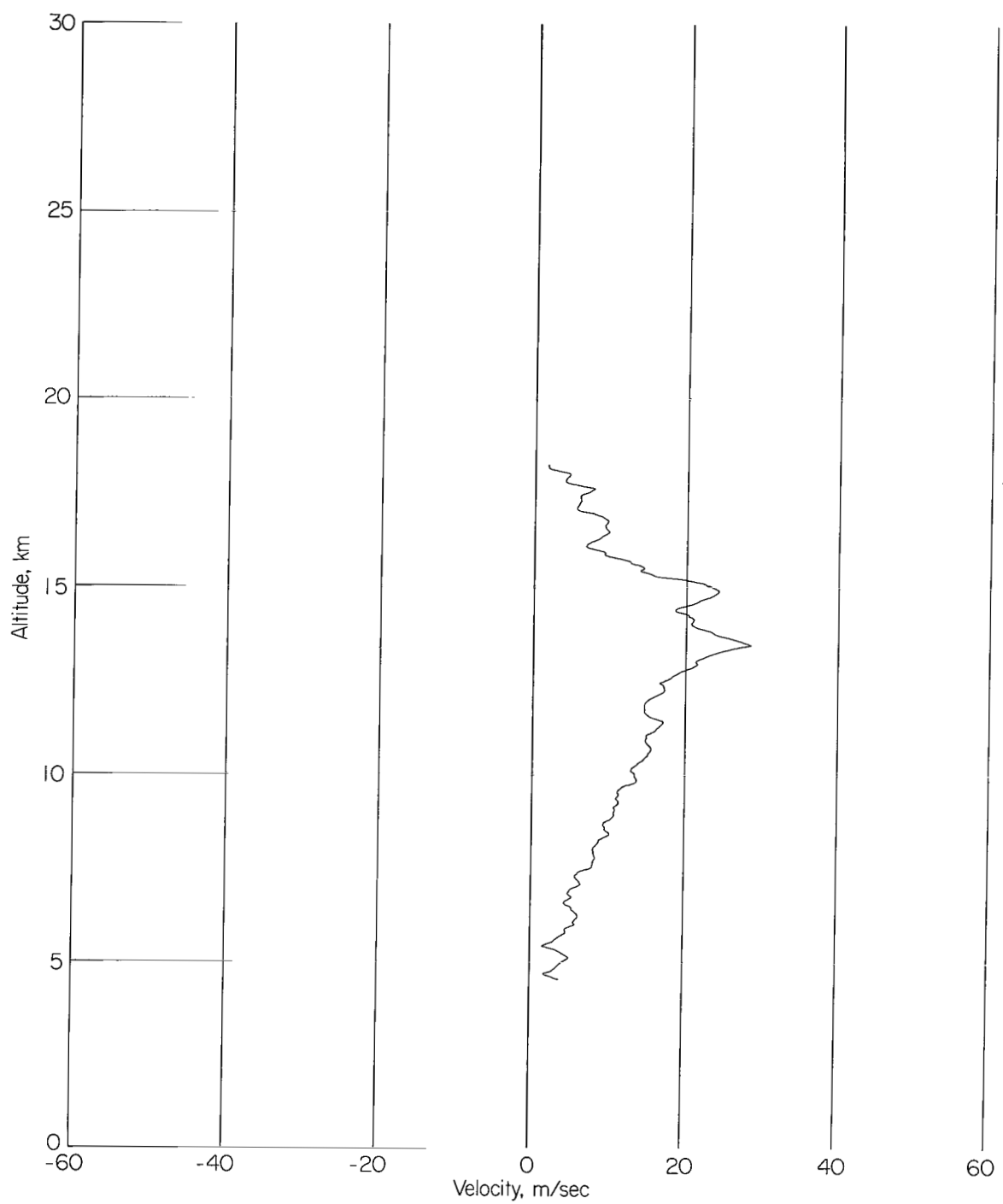(b) South-to-north velocity component.

Figure 13.- Concluded.

(a) West-to-east velocity component.

Figure 14.- Smoke-trail wind profile obtained on December 4, 1962. Trail 314; time interval of 60 seconds; height interval of 25 meters.

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(b) South-to-north velocity component.

Figure 14.- Concluded.

49

(a) West-to-east velocity component.

Figure 15.- Smoke-trail wind profile obtained on December 6, 1962. Trail 315; time interval of 60 seconds; height interval of 25 meters.
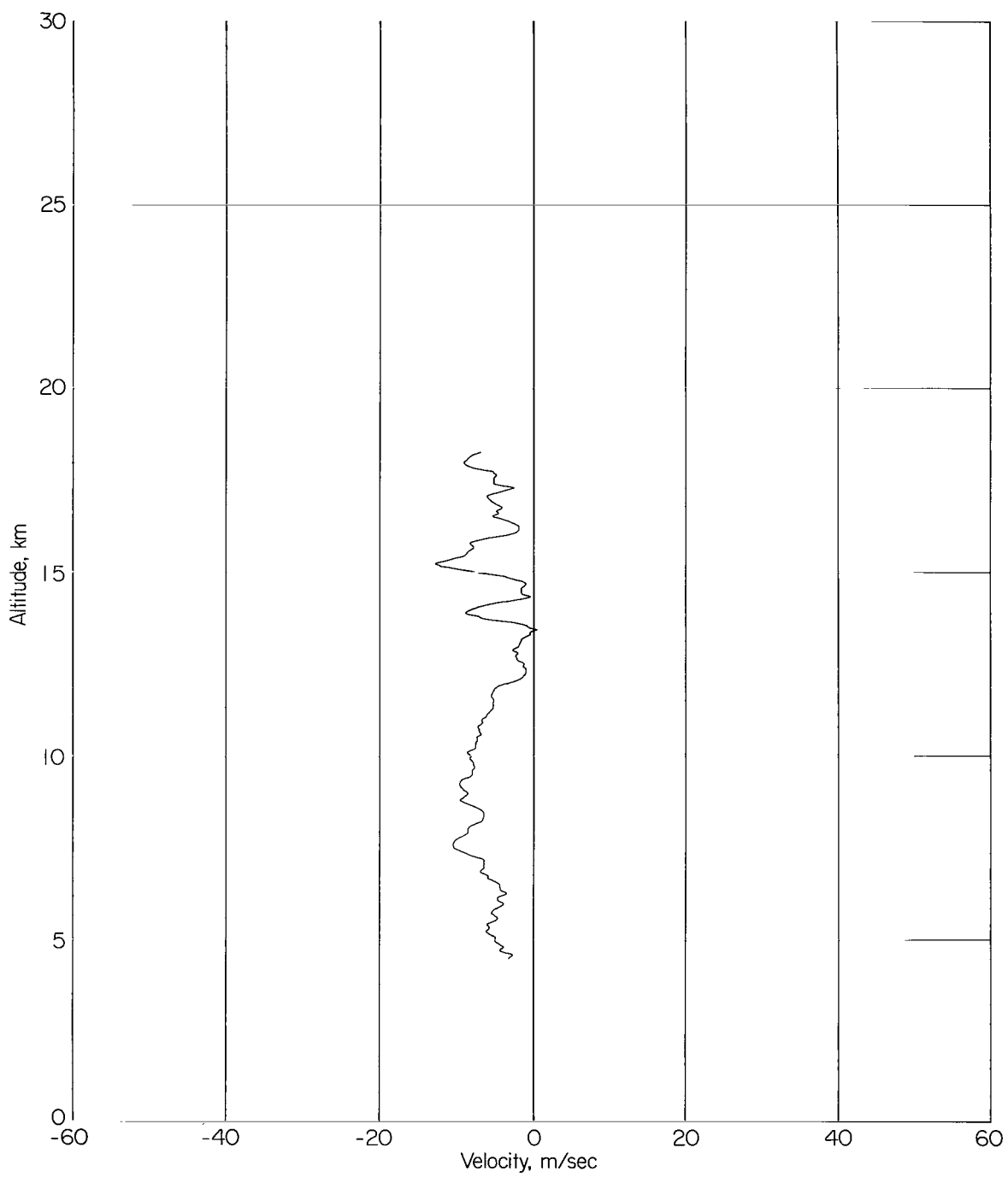
(b) South-to-north velocity component.

Figure 15.- Concluded.

(a) West-to-east velocity component.

Figure 16.- Smoke-trail wind profile obtained on December 10, 1962. Trail 316; time interval of 60 seconds; height interval of 25 meters.

(b) South-to-north velocity component.
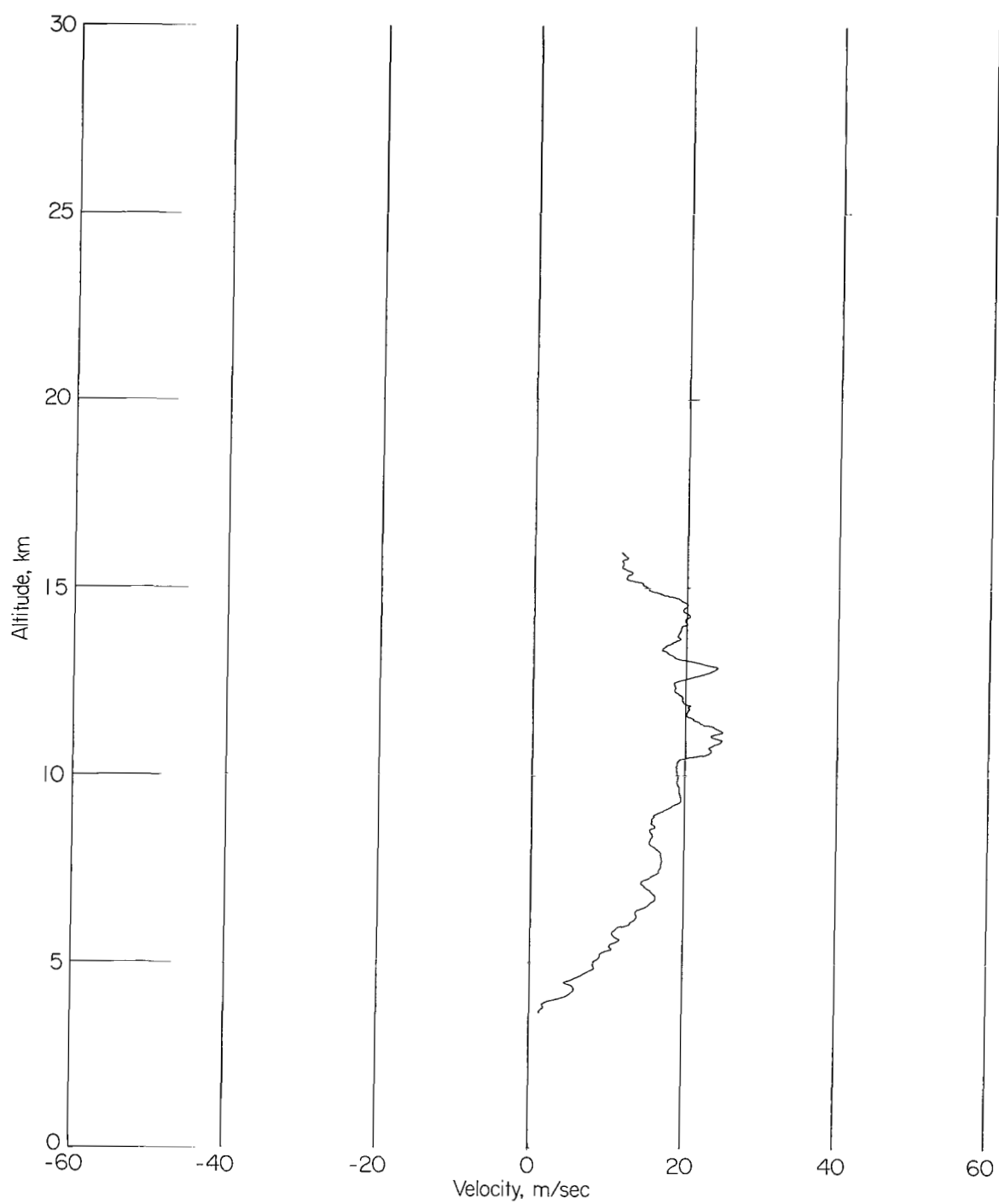
Figure 16.- Concluded.

(a) West-to-east velocity component.

Figure 17.- Smoke-trail wind profile obtained on December 11, 1962. Trail 317; time interval of 60 seconds; height interval of 25 meters.
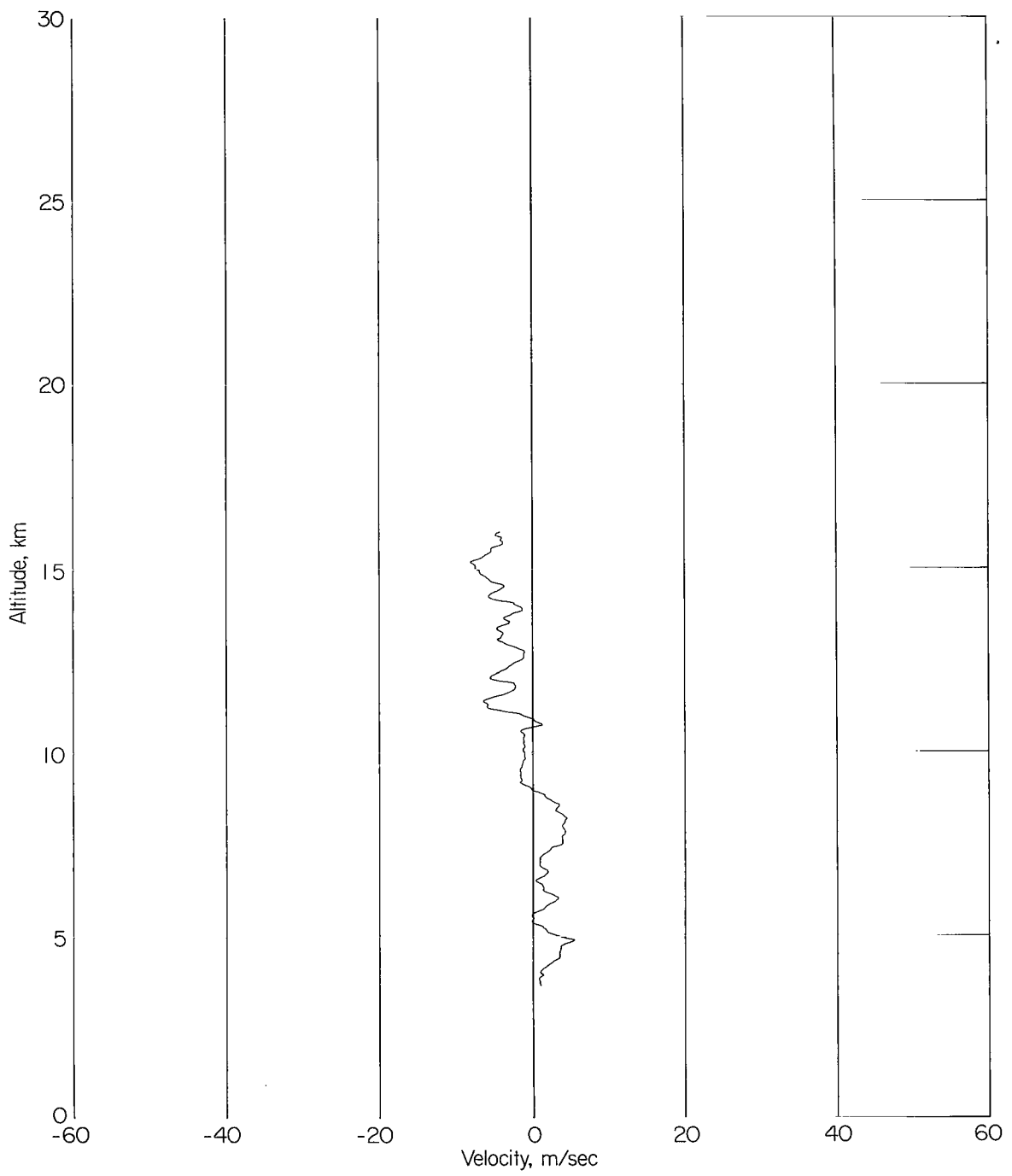
(b) South-to-north velocity component.

Figure 17.- Concluded.

(a) West-to-east velocity component.

Figure 18.- Smoke-trail wind profile obtained on December 13, 1962. Trail 318; time interval of 60 seconds; height interval of 25 meters.

(b) South-to-north velocity component.
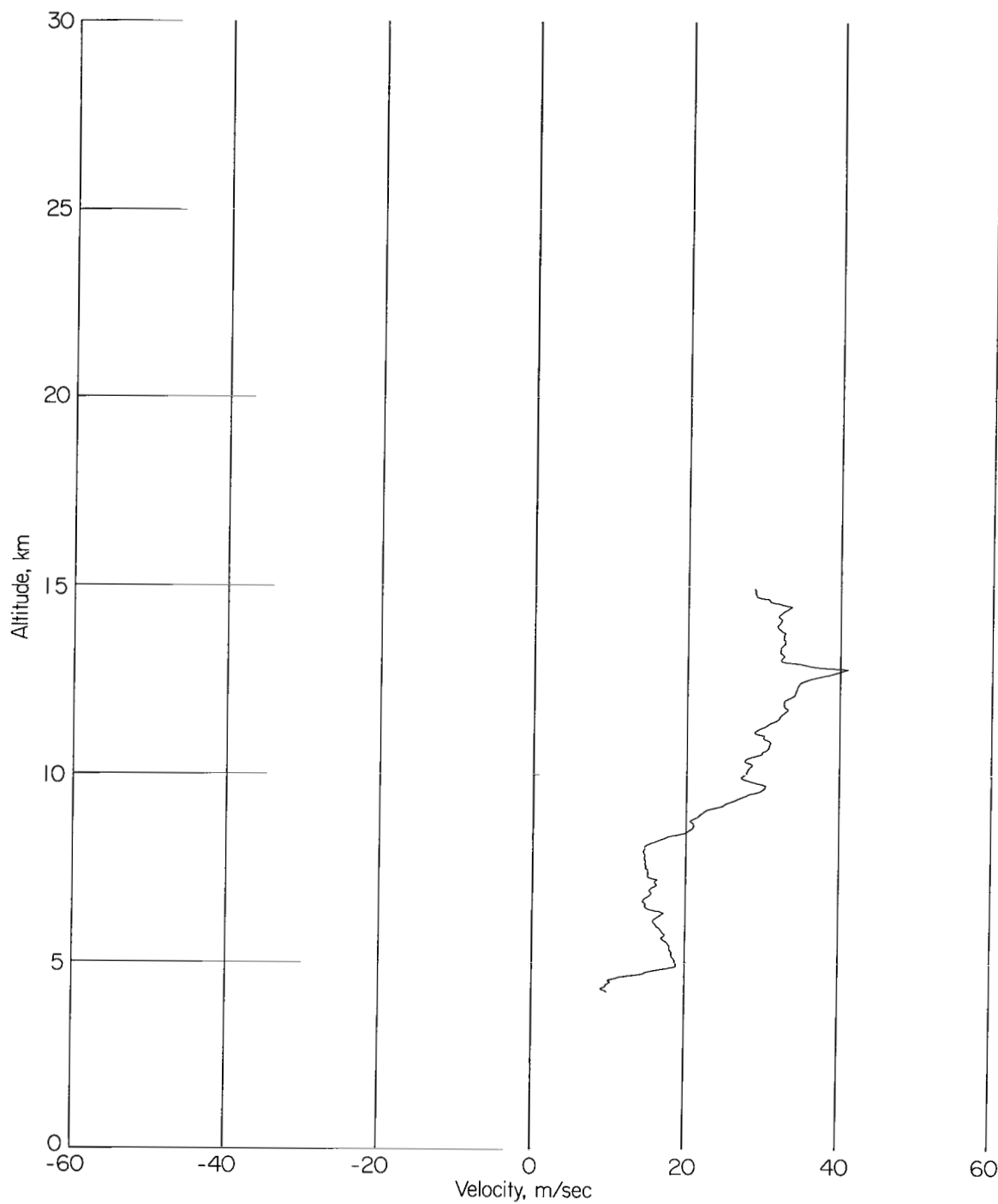
Figure 18.- Concluded.

(a) West-to-east velocity component.

Figure 19.- Smoke-trail wind profile obtained on December 14, 1962. Trail 319; time interval of 60 seconds; height interval of 25 meters.
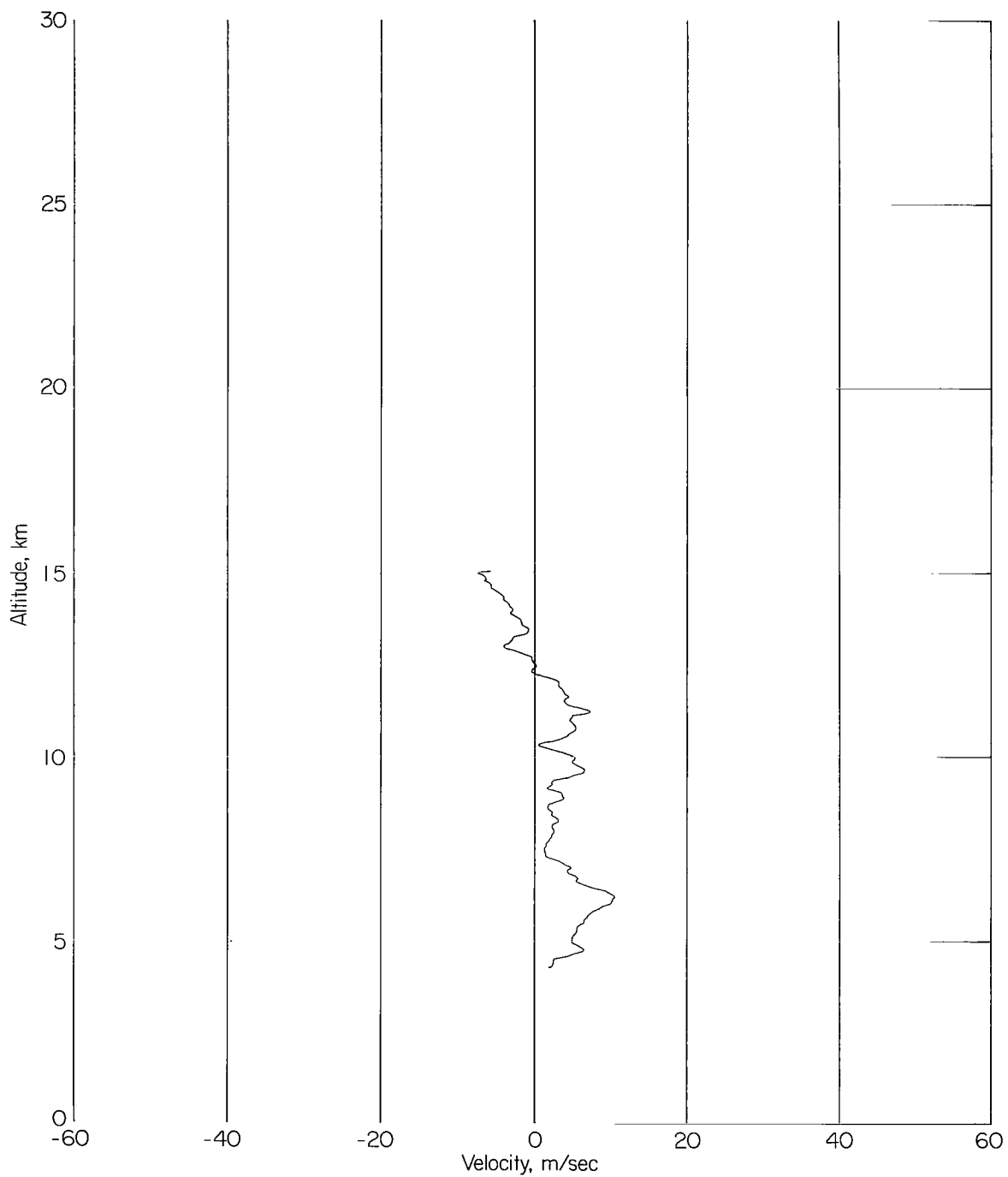
(b) South-to-north velocity component.

Figure 19.- Concluded.

(a) West-to-east velocity component.

Figure 20.- Smoke-trail wind profile obtained on December 17, 1962. Trail 320; time interval of 60 seconds; height interval of 25 meters.

(b) South-to-north velocity component.
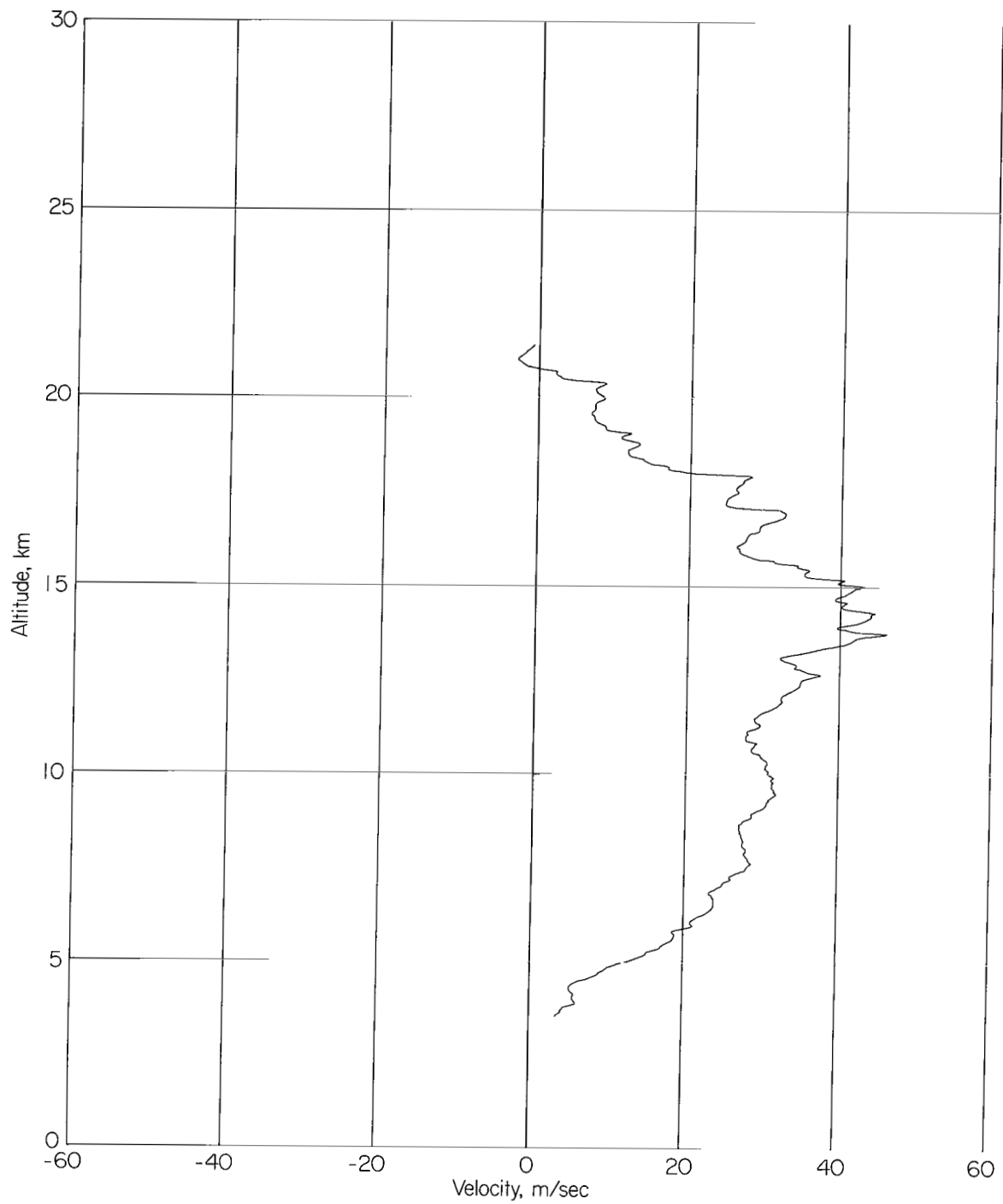
Figure 20.- Concluded.

(a) West-to-east velocity component.

Figure 21.- Smoke-trail wind profile obtained on December 18, 1962. Trail 321; time interval of 60 seconds; height interval of 25 meters.
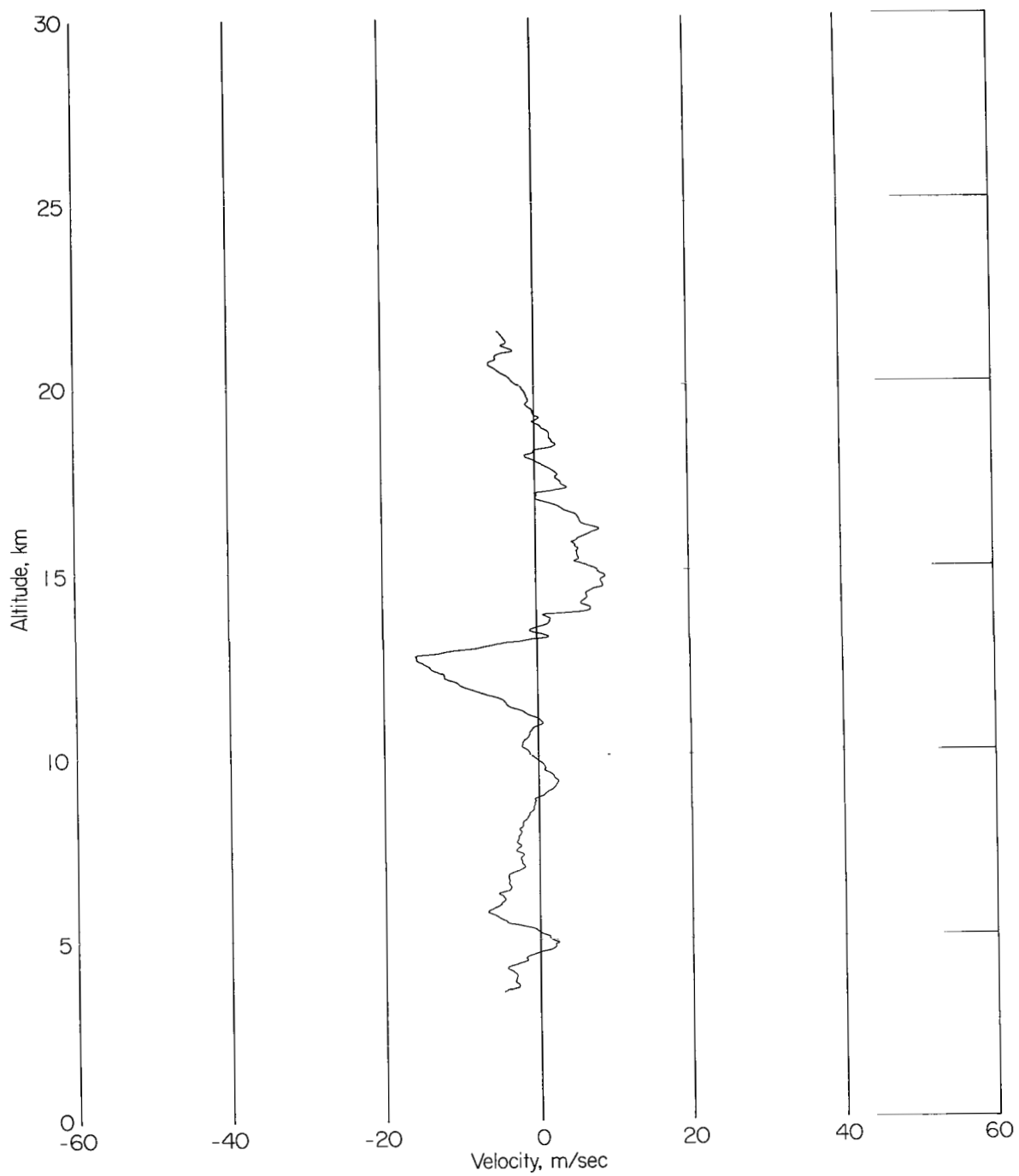
(b) South-to-north velocity component.

Figure 21.- Concluded.

(a) West-to-east velocity component.

Figure 22.- Smoke-trail wind profile obtained on December 19, 1962. Trail 322; time interval of 60 seconds; height interval of 25 meters.

(b) South-to-north velocity component.
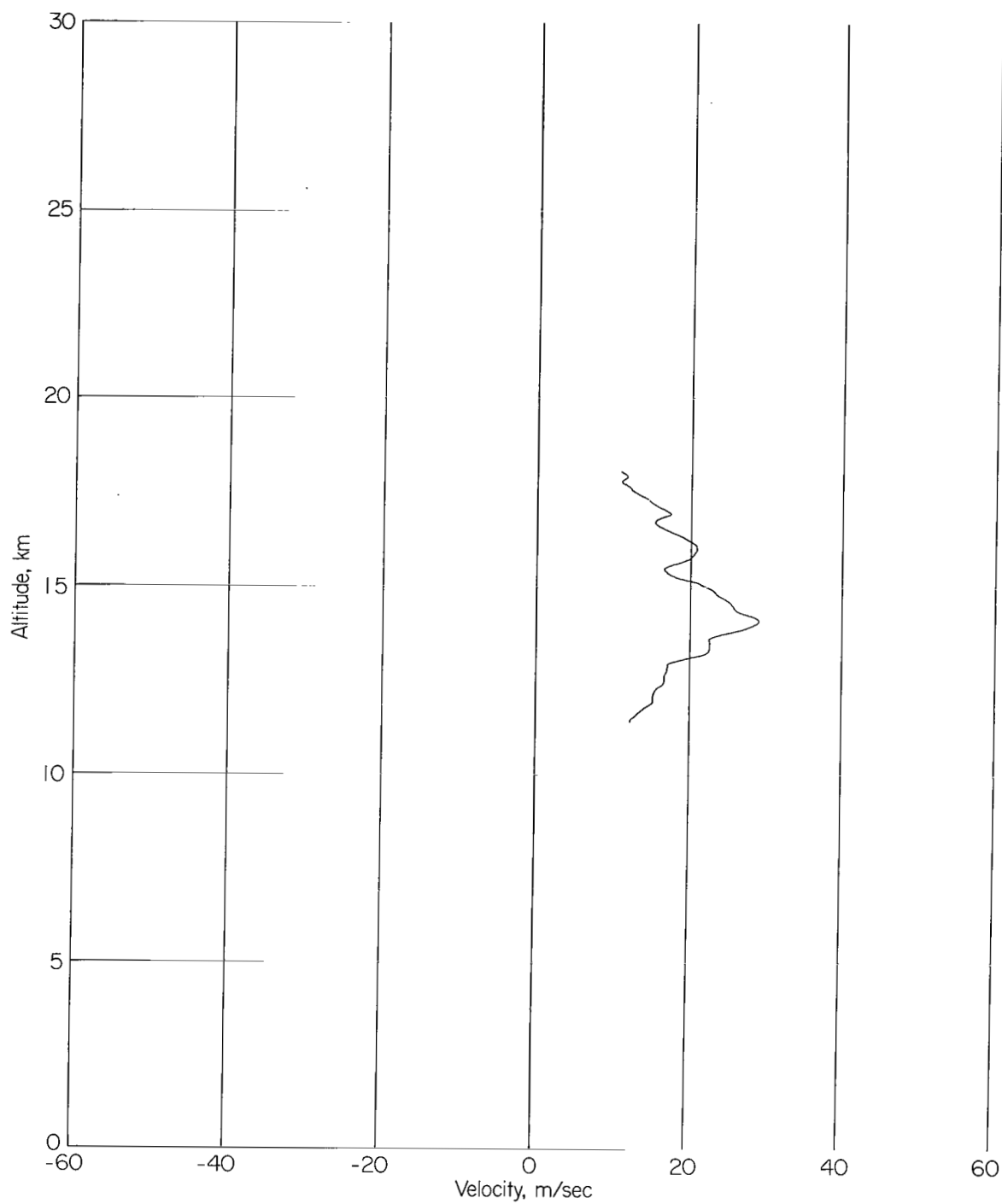
Figure 22.- Concluded.

(a) West-to-east velocity component.

Figure 23.- Smoke-trail wind profile obtained on December 20, 1962. Trail 323; time interval of 60 seconds; height interval of 25 meters.

(b) South-to-north velocity component.

Figure 23.- Concluded.

(a) West-to-east velocity component.

Figure 24.- Smoke-trail wind profile obtained on December 21, 1962. Trail 324; time interval of 60 seconds; height interval of 25 meters.

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(b) South-to-north velocity component.

Figure 24.- Concluded.

(a) West-to-east velocity component.

Figure 25.- Smoke-trail wind profile obtained on December 28, 1962. Trail 325; time interval of 60 seconds; height interval of 25 meters.

(b) South-to-north velocity component.

Figure 25.- Concluded.

(a) West-to-east velocity component.

Figure 26.- Smoke-trail wind profile obtained on November 16, 1962. Trail 368; time interval of 60 seconds; height interval of 25 meters.
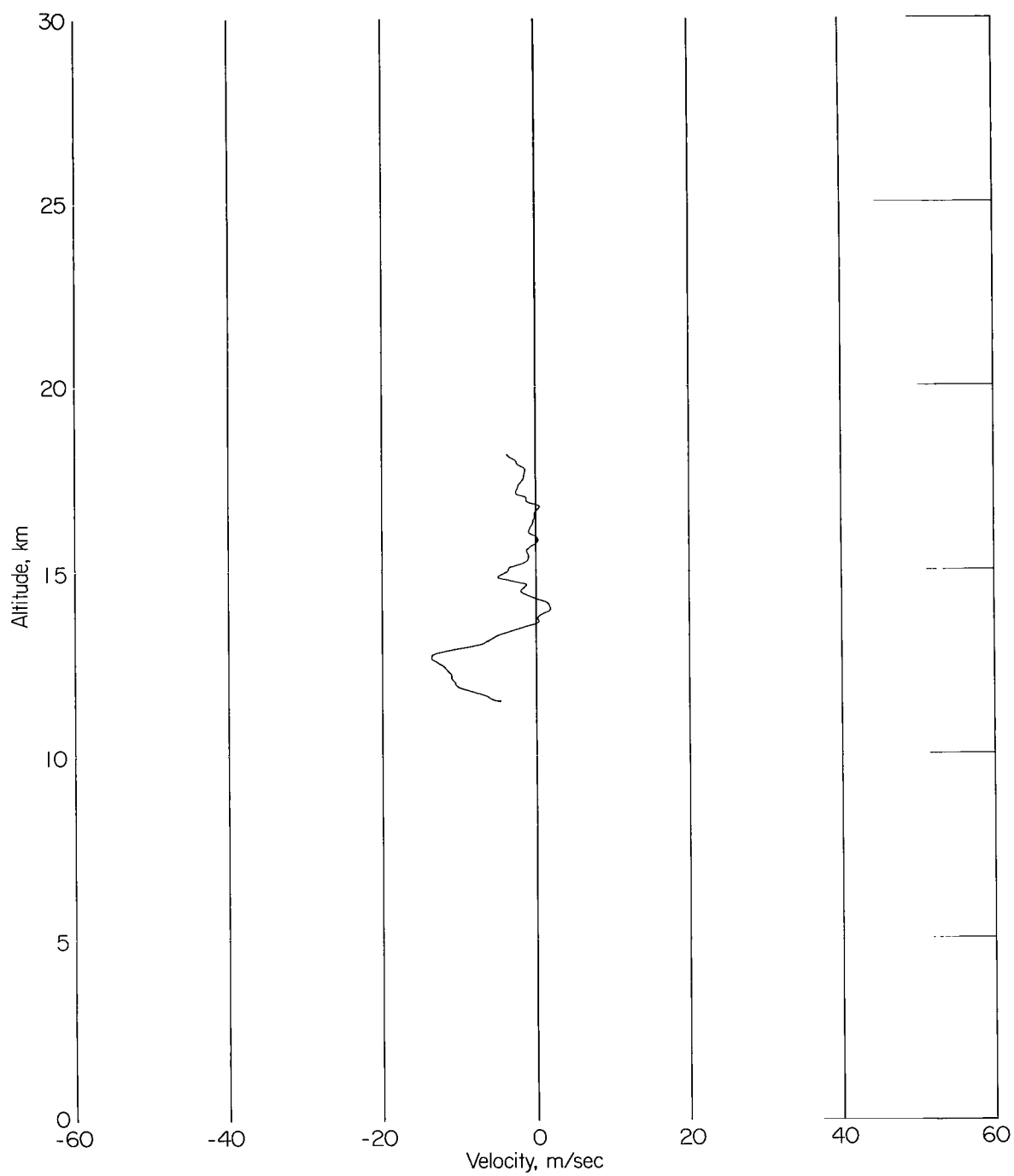
(b) South-to-north velocity component.
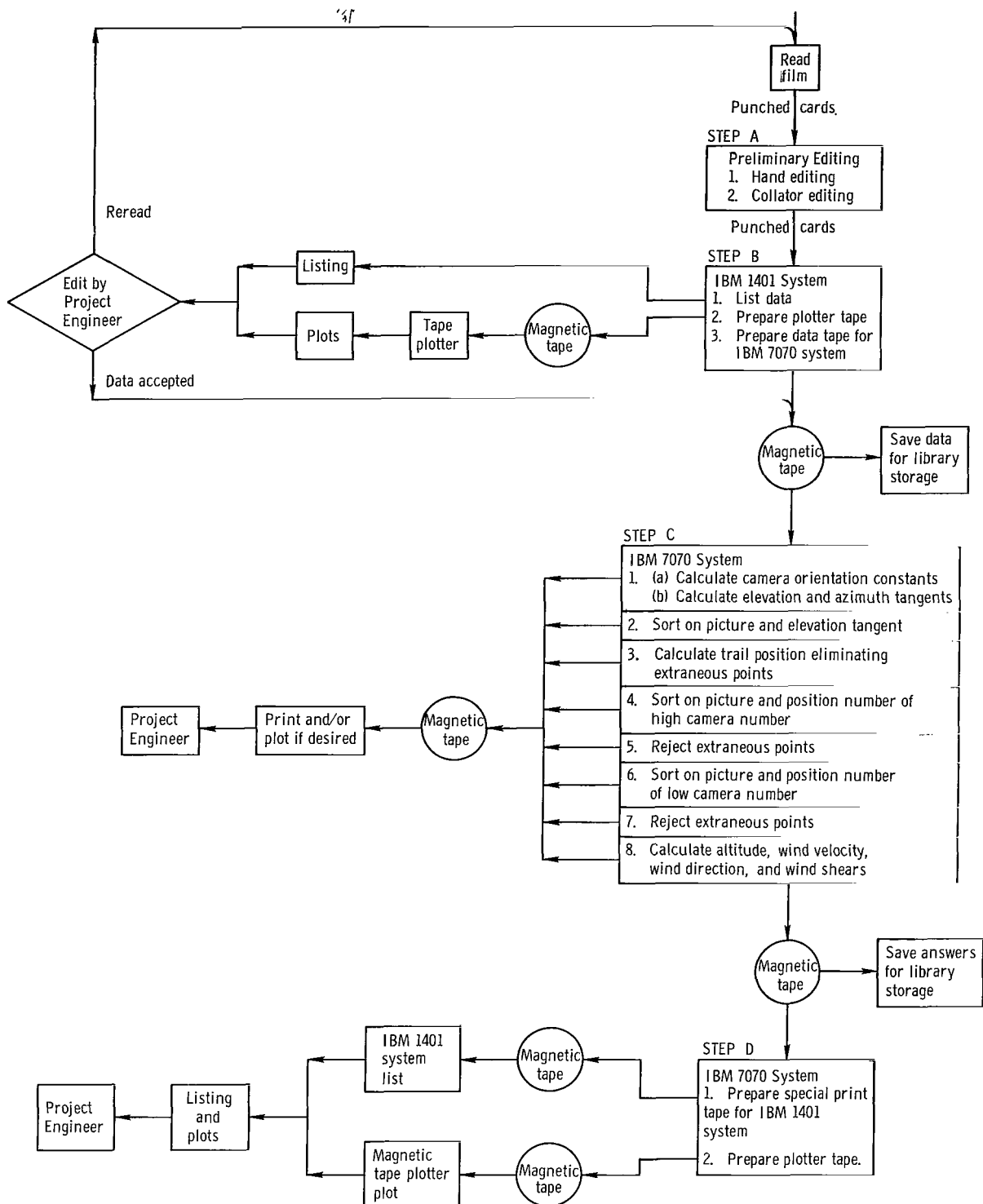
Figure 26.- Concluded.

Figure 27.- Flow diagram of data reduction procedure.

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